Scottish Curling-Ice Group

PEBBLE

Overview

There are as many definitions of the "perfect pebble" as there are curling rinks and curling-ice technicians. Essentially pebble is used to provide a consistent playing surface that should remain so for the duration of a game, and in serious competition this is generally achieved. However, in many rinks the lack of time between games has led to several pebbles being applied in succession, until consistency is compromised and, eventually, sacrificed. In days gone by this was considered acceptable, with the ice declared "the same for both sides", while the modern game of precision now demands a degree of perfection only highly competent curling-ice technicians can achieve and maintain from game to game.
Is this high standard necessary? Can it be achieved? How difficult is it? Yes, yes, and not very.
From the report on *Why do curling stones curl* it is clear that there are no universal answers, only influencing factors. Quality of water, temperatures, humidity, heat transfer and the qualities of the stones in play all have an influence, and as one parameter changes the others have a different influence than before. Nothing is truly as it seems, leading to great confusion and many theories. However, research has shown that, for a given set of well-matched stones, there is a fair amount of leeway in the application of the parameters before the stones will no longer do what they can normally be expected to do. Yes, a high standard of consistency can be achieved if the technical lessons are applied; yes, it can be achieved by any competent curling-ice technician who is dedicated to the challenge; and yes, because of the amount of leeway, it is not difficult to maintain from game to game.
It is the purpose of this report to examine all aspects involved in pebble and, by using information now freely available through *Curling Ice Explained*, demonstrate the factors involved and how they can be achieved and maintained.

History

Curling ponds were scraped clean with an assortment of scraping implements and nowadays even with a powered precision cutting machine. This created a reasonably level and flat surface without pebble, on which the early games were played with some difficulty. Who knows, perhaps one day it rained briefly, creating a pebbled surface that played differently and, ignoring complicating factors, very much easier. The lesson was learned and applied by alert ice technicians, all competing with each other to provide the best ice. Considering the influencing factors it is clear that true curling ice would have been near impossible, because there was little or no control of any of the parameters, yet this kind of surface is still in use today even in curling rinks where the parameters can be controlled.
The most common scenario found in curling venues such as skating arenas used for occasional curling is to scrape the surface as level as possible, sprinkle water on it and freeze the floor colder than usual. In the older curling arenas this was not much different, and at an ice-surface temperature (IST) of – 5ºC or colder even outdoor ice would have played the same as indoor ice at that temperature. At this temperature a hose can be used to apply the pebble with little real effect on consistency, and for decades no-one would have known better. The fact of the matter is that this ice would be quite keen, even fast, and by modern standards this is not necessarily curling ice.
To improve their lot, or demonstrate a dubious skill not mastered by other technicians, pebble heads were made. Some were long pipes, or short pipes, or flat pipes, or round pipes. Some had a few large holes, or a few small holes, or many small holes. Even today some technicians still use such heads, with two or three holes of about 5mm in diameter to distribute water in some haphazard way. This is sprinkled water, not a carefully applied pebble, and the result will not be much different from those very early days on an outdoor pond when a shower of rain passed overhead.
Some clever technicians would soon discover that stones had an influence. A large, flat surface underneath would help the stones to travel further and, by roughening the surface of the stones, they would curl more in those cold, uncontrolled conditions. Even this is still done today, and research suggests that it is usually done in venues that have a low air temperature (AT) and so a low IST. By using tap water for the pebble they had little choice, any warmer and the stones would dive to anywhere, so a norm became accepted simply by the dictates of necessity and the art of the unscientific possible.
Modern curling stones now have a cup within the bottom surface, creating a running band of 5-10mm wide, some 120mm in diameter. Anyone who thinks that the pebble of old is suitable for today should try and play a modern stone on an outdoor pond – it simply does not work. Modern stones need a modern pebble, without which it does not behave like a modern curling stone.

Water quality

The water in any lake or pond is the product of its environment, and any environment from which it flowed. Because water tries to dissolve any substance it contacts, it will try to dissolve metals, salts, acids, dust and dirt as far as it goes. It is conceivable that some waters will be very clean compared to others, while some waters will be so dirty that nothing can live in them. The impurities will be trapped when the water freezes, and released when the ice is thawed.

Sprinkle a little water onto an ice surface and it will melt the surface, for however a short period, and lift salts into the drop of water. The salts will concentrate in that part of the drop that freezes last, the very top, which is the area in contact with a curling stone. Because salts lower the freezing point of water the surface will be warmer than it would – or should – have been, and it will behave very differently in contact with the stone, unless the water is frozen colder to compensate. Suddenly the IST has to be colder than –5ºC, resulting in keen and straight ice.

Many arenas and curling rinks use well water for their supply, with similar consequences. Most rinks in fact still use tap water to install their ice, along with the many chemicals used to render the supply safe for drinking. Technicians have learned to remove the salts in a systematic way because the bulk of it is trapped in the surface – by cutting the surface between floods, and then pebbling and cutting several times after the final flood, most of the salts can be removed. The water quality at the end might not be totally pure, but it will be infinitely cleaner than before and should be perfectly suitable for curling. However, even if totally pure water is used for pebbling, a small amount of salts will still be lifted into the tops of the pebbles to affect the behaviour of the stones.

To overcome this problem it is now the norm to install ice for competitions by using purified water. This could be deionised water, water cleaned through reverse osmosis, filtered or even distilled water, and then there is Jet Ice. Although several attempts have been made to learn and understand what Jet Ice actually is, the suppliers are not yet willing to provide any valid scientific answers, and their product cannot be evaluated here. What is however clear is that the best curling-ice technicians now use clean water to install their ice at serious competitions, to minimise the effects of impurities and give them better control over the behaviour of their pebbles.

It will be some time before clean water will become the norm in curling rinks, but most modern rinks are now able to afford deionised water for installation and as the demand grows, so will the means to supply at a cost-effective rate. An ice pad made of deionised water is very different to one made of tap water, more consistent, stronger, cleaner and more appropriate for use as the base level of a curling pad, and ultimately cheaper to use and maintain.

The Ice Pad

The level of an ice sheet can mean many things (see the report on Level). In the case of a lake it might not be considered level at all because of the curvature of the earth, yet it is according to definition. Within the walls of a curling venue the problem is less severe, but even here it would be wrong to assume that water will "find its own level". It might do so and it might be level, but it might not be straight, even or flat.

Water is used for curling because of two principal reasons: it can be used to create a near-perfect level surface, and it can be pebbled to use the properties of water to facilitate a game of curling. Installing a level ice pad is a highly skilled exercise in the modern environment, drawing on many branches of science and considerable experience of ice technicians. Installing the ice pad is only the start of the process, it then has to be maintained as a level surface, and that is a science and skill on its own. In days gone by when heaving was a common problem only additional flooding during the season could overcome the irregularities, while in today's rinks with insulated concrete floors and heat mats to prevent permafrost some technicians are now able to maintain a near-perfect level for many months on end without flooding. Flooding should be seen as the method through which an ice pad is installed, with every flood more level than the previous one, and after some ten to fifteen floods the ice surface should be perfectly level.

What constitutes a perfect level is relative to its application. If curling stones can be played down some fifty metres of ice and behave exactly the same down any chosen line, the ice could be considered perfectly level, yet tests have shown that the stones will not find an irregularity if the ice is level within 0.05mm over the width of a sheet of curling ice. Furthermore, the stones are travelling on pebble which raises the surface by as much as 1mm in a very irregular way due to the varying height of the pebbles, and it could almost be argued that stones will not find irregularities less than 1mm.

Using a laser level to check the level of the ice surface will provide readings that are accurate within 1mm, but no less. This is useful when checking the level of an existing pad, and of course the level of the concrete floor before installing the ice, using the information to improve the level through further floods. The laser level is not however accurate enough to tell whether a perfect level has been established. To overcome this problem a new device, the IcePOD (Precision Overhead Device), was created, which provides readings accurate within 0.01mm over the width of a sheet. This device uses a metal frame that tensions a thin cable between its ends, from which a precision dial is suspended to take the readings. It is surprisingly accurate and, if used correctly, cannot lie, and at last it is possible to tell just how level an ice pad in fact is. By using the IcePOD technicians have learned from their mistakes and how to correct them; it has enabled them to level a pad within 0.02mm over the width of sheet and to keep it there for many months, saving much work and resulting in excellent curling conditions. The time will surely come when all curling rinks of note will have such a device as standard equipment, not only to occasionally check the level of the pad, but also to measure the height and wear of pebble at different sizes and temperatures and so improve the quality of the product for the game of curling.

The equipment

To spray a sheet of ice with a hose is not too difficult, but it cannot really be called pebbling. More conscientious technicians knew that it simply wasn't good enough and tried other ways, finally using a container of some kind with a short length of hose attached to it. To increase the pressure the container had to be lifted onto a shoulder, while the early pebble heads were primitive and very much restricted to the smallest holes they were able to drill into the copper. This was altogether an awkward business and, in the hands of better technicians, a skill much admired, but by today's standards it can almost be described as a waste of time.

As the pebble heads improved and plastic became common, shoulder cans were made that could hang from a strap. These worked better and many are still in use today, but carrying a can of water from the same shoulder for a few years did much damage to the backs and bones of technicians, who now pay the price in old age. Anyone who has had to pebble six sheets at a time for six draws a day will know that the shoulder can was far from ideal and, even at the best of times, very hard work.

The backpack can was inevitable. Most of these are adapted from a gardener's spray and can hold as much as 25 litres of water, and some technicians even leave the pump fitted to pressurise the can. This is no longer necessary, as more even distribution can be achieved simply by using gravity. Carrying 25 litres of water about is not necessary either, as 15 litres is more than sufficient to pebble four sheets twice for normal play. But the principle of the backpack can is a good one, especially if it sits high on the back for that extra bit of pressure, and it pays to spend some time on the can to ensure that it works just so.

Experiments over several years resulted in the tests reported in *Pebble can tests*, and continuous refinement of the backpack can used today. The following have been found to be important factors when preparing a can for individual use:

- The can must hold at least 12 litres of water to avoid constant refills. Using a fine or extra-fine head at the proper speed and rhythm will use 3 litres of water to pebble one sheet twice, or 12 litres for four sheets. The can illustrated in the report holds 13 litres when full.
- It must not leak. The plastic connectors supplied with the can are useless and should be replaced, preferably with a brass connector and elbow as shown, using silicone sealant to ensure proper bedding when connecting to the can.
- The inside diameter of all pipes and fittings must not change, even for a very short distance. A diameter of 18mm has been found to be easily achievable and will provide a smooth, even flow. Any obstruction in the flow will affect the distribution of pebble.
- The pipe from can to hand must be flexible, strong, light and with a smooth inside surface. Tricoflex pipe of 18mm inside diameter, also recommended for flooding hose, has been found to be the best by far, and not expensive.
- The length of pipe is critical and must be adjusted to suit the technician's arm length until it is comfortable to use and cannot kink when in use. The connection with the brass elbow by means of a piece of copper tube MUST be clamped, but where the Tricoflex meets the copper extension pipe it is better to tape the connection rather than use a clamp, as the latter will rub into the palm and cause a blister.
- The extension pipe too must be made to suit the technician, with a length somewhere between 150 and 200mm. Find the lighter gauge of copper used by professional plumbers rather than the thicker pipe sold to DIY plumbers – it makes a big difference in controlling the weight.
- Cushioning the hand area with something is a good idea, but be sure to use a material that absorbs moisture, as sweat from the hand will soon make it impossible to grip the pipe properly. Foam tubing works well, but the foam does deteriorate and will need regular replacement.
- The connection to the pebble head must be sure, leak proof and as light as possible.

The can as described above will provide a flow rate of around 0.3 litres per second (without pebble head), which is ideal for most pebble heads. However, due to the infinite variations of arm length and strength, rhythm, temperature of water and speed of walking, only experimentation and practice will develop the best result. It has been found too that every pebble head has its own requirements for even distribution, and the recommended speed and rhythm for a fine or extra-fine head will be around 80 to-and-fro swings in 40 seconds from backline to backline (about 38 seconds per litre).

The most important piece of equipment for producing the perfect pebble is of course the pebble head. It is usually made of two halves of copper soldered together, with a fitting that screws or fixes to the copper extension pipe. The diameter of this fitting must not restrict the flow but continue the 18mm constant inside diameter. The holes must be well distributed and clear, both size and number varying according to the intended purpose. Members of the SCIG all use heads supplied by Shorty Jenkins, usually a fine (65/0.50mm) or an extra-fine (65/0.45mm) for the game pebble, as these heads have been found to be superior to all others tested.

Properties of water

Water is a complex substance with many anomalous properties, and fortunately not all of which are relevant to pebble. It is an excellent solvent, which affects both density and viscosity – should any chemical be mixed with it the resulting liquid will no longer be water and will behave differently. Clean water provides the best pebble, and only clean water must be used, usually deionised water.

Water reaches its density maximum at 4ºC, which means that all of a body of water must be close to +4ºC before it can freeze. Should the water be warmer, say 60ºC, the drop will take longer to freeze and will have a different shape to a drop of water at 35ºC. A drop that freezes too fast will be more brittle than a drop that freezes slower, while a drop that freezes at the optimum speed will be stronger than a drop freezing too fast or too slow. It is difficult to define exactly what the speed should be due to the many complicating factors involved through temperatures and humidity, but clean water at 35ºC applied at the speed above onto an ice pad at – 4ºC freezes beautifully within seconds and lasts extremely well.

The opposite properties of warm and cold water can lead to confusion when trying to analyse a problem, especially at lower temperatures, as can the fact that hot water may freeze quicker than cold water. These anomalies are best left to the scientists, except to remember that water has its own rules and needs to be studied with caution and much patience.

The high surface tension of water is one of its most useful qualities in curling ice, which helps in the flooding process and also the pebble. The high viscosity of water, accelerated at low temperatures, allows for the pebble to sit up and freeze high, rather than flatten out and become a low mound. This is why water for a playing pebble should not be too warm, and 35ºC is a good starting point to develop from under normal conditions in Scotland.

Free oxygen in the pebble water will cause the pebble to be weaker, with small bubbles of air within each pebble. Heating the water will remove most of the free oxygen, and 35ºC has been found to be sufficient. With less trapped air the pebble will have better thermal conductivity and will last longer under the pounding of granite, teflon, brushes and pads.

Water molecules will readily attach to dust in the air and trap the dust within each drop. As the drop freezes the dust will usually migrate to the top of the pebble to create increased friction, and under some conditions this can make the pebble unplayable after two or three ends of curling. Under conditions of high humidity and low air temperature moisture from the air will gradually find its way to the ice surface and the tops of the pebble, taking with it particles of dust or floating fibres, where the stones will rub the dirt off for it to freeze to the running bands of the stones. This will cause the stones to draw increasingly more and by the sixth end perhaps some 12 foot. Clean air, clean walkways, clean clothing and clean ice will all contribute to a clean pebble and a good game of curling.

Temperatures

In Section 13 of *Curling Ice Explained* (WCF) there is a comprehensive look at temperatures and parameters in a curling venue. Here the emphasis is on how the pebble can be affected by changes in the temperatures, especially the roof temperature (RT), the air temperature (AT) at 1.5m and the IST. The target parameter for the ice surface is about – 4.5ºC with the AT about 8ºC, while the RT will vary from place to place. Maintaining the AT and IST within 0.2ºC is not easy, but by tracking the RT it becomes easier.

A study done at Forest Hills, Scotland, used three thermo-hygrometers with radio transmitters mounted at 1.5m, 3.0m and 4.2m to track the changes in roof temperatures. It was possible, very quickly, to control the AT simply by controlling the heat supply to the roof space, and to control it very accurately (within 0.2ºC) for the length of a competition. The heat was simply never a problem.

An IST of – 4.5ºC does not remain constant. Body heat from curlers (and spectators, in arenas) contribute significantly to the heat load in the building, and this heat will generally move upwards towards the roof. Turbulence from fans and movement of players will help the heat to move downwards again, onto the pebble and the ice surface, and the IST will quickly rise unless this heat is extracted by the refrigeration plant. In fact, in most buildings ALL the surplus heat in a rink will have to be extracted through the ice – if it is not, the pebble will be too warm and will wear quickly or "go flat". Should the IST rise to – 3.5ºC the relationship between stone and pebble will change dramatically, causing the stones to draw excessively and become sluggish. Underfoot the ice will become very slippery to the curlers and often the first signs of such a calamity will be when curlers start to slip and fall. By controlling the amount of heat in the roof space, and primarily by decreasing the amount of heat in advance of a game, the roof space can be used as a reservoir for surplus heat until the plant catches up again, making it much easier to control the IST.

The relationship between the IST and the humidity in the rink is also very important to pebble. Normally technicians will try to keep the relative humidity (RH) at 40-50% (at 1.5m), with the AT at 8ºC and the IST at – 4.5ºC. At this level the dewpoint temperature will be around – 4ºC with virtually no frost on the ice surface. Should the humidity remain constant but the IST should fall to say – 5.5ºC, there will be no frost on the ice surface and the tops of the pebble will be too cold for the stone to interact with it, resulting in straight and keen ice. In the report on *Why do curling stones curl* the importance of amorphous ice (frost) on the ice surface is studied, and from the report on *Sweeping and ice temperature* it is clear that the amorphous ice plays a very important role, much more important than the surface temperature (see below).

In colder countries with significant snowfall it is not uncommon for the AT to remain as cold as 2ºC, with an RH well below 20%. Due to a very low heat load and no amorphous ice on the surface of the cold pebble, technicians have a different problem in producing the required draw. Without a humidifier to introduce moisture, or a heating system to raise the AT and so the influence of heat on the surface of the pebble, they resort to roughening of the running bands of the stones to increase friction and draw – the stones slow down and draw more.

Because these very small changes in temperature on the ice surface, as well as the amount of amorphous ice that has formed, are so difficult to measure, it will be some years yet before methods can be developed to fully explain what happens under a curling stone. The sum of knowledge thus far does however suggest clearly that the surface of the pebble, made with clean water, needs to be at the correct temperature all the time, and must have at least some amorphous ice to allow for an even MSMM/F effect (mini-second micro-melting and freezing). Get it right and the stones will play beautifully; get it wrong, and the game will not be the same.

Humidity

In the report on *Water in a curling rink* there is much information on the effects of humidity on the ice surface. From the above it is already clear that, for a given set of parameters regarding temperature, there is a stage where humidity levels will be healthy, with controllable amorphous ice and low heat transfer. At Forest Hills, a known humidity black spot with the sea, mountains, a loch and near-continuous rainfall all competing for the same air, the RH could vary from 40% under the best conditions to 90% under the worst. Despite these high levels of humidity it was possible to produce some of the best curling ice to specification on a daily basis, by manipulating temperatures and careful control of the ice surface through regular cutting. Healthy humidity is therefore not a simple RH figure, but control of its possible effects on the ice surface. Only when control becomes impossible should humidity be considered unhealthy.

The biggest single problem caused by unhealthy high humidity is condensation. At the worst end of the scale will be condensation in the roof space, resulting in dripping onto the ice surface which not only creates those tennis balls of ice, but also makes the surface slippery from the splatters that have yet to freeze. A relatively unknown effect of condensation is the release of energy which, if the condensation is directly onto the ice surface, will result in an immediate increase of the IST by as much as 1ºC. This increase will not only cause the stones to behave radically differently, it will also make the surface very slippery for a few minutes, until the heat is extracted by the plant and the IST restored to a safer temperature.

When the humidity is very low, some strange things can happen too. It has been observed in deserts that a shower of rain does not always reach the ground, simply because the air is so dry that the drops evaporate before they get there. The same can happen to pebble, where a medium pebble will become a fine or even an extra-fine as it evaporates on its way down to the ice surface. Another problem is sublimation, where the ice evaporates directly into vapour to compensate for the low humidity, absorbing substantial energy and immediately lowering the IST.

Size and shape

It is not clear how to define the size or shape of pebble. The hole of an extra-fine pebble head is drilled with a bit 0.45mm in diameter, and if the hole is clean and uniform it will allow a certain amount of water through it. If the water is warm it will be less viscous and produce smaller drops, which will take more time to freeze once the drops hit the ice pad because of the warmth (or less time because of the size); if the water is cold it will be more viscous, produce larger drops and these will freeze faster (because the water is cold, or slower because the drops are large). Or will they, considering the Mpemba effect where warm water can freeze faster than cold water, or will the cold water contain more free oxygen and take longer to freeze, or will the RH be too low and some of the water will evaporate on the way to the pad to create smaller drops that freeze faster. Then there is the thickness of the copper used for the pebble head, where a thin copper will cut the drops smaller, or a sharp edge to the holes that will cut the water better, or the swing of the arm can be vigorous and cut the drops better. The possibilities are endless.

At Forest Hills the same extra-fine pebble head (65/0.45mm) was used for two full seasons, ten months per season, every day, for all the playing pebble. As the holes developed scale the drops became smaller, and when the corner guards appeared the head was cleaned and every hole carefully checked for blockages. Suddenly the drops would be bigger again through the clean holes and the distribution more even, until the process was repeated. After two years there was some visual evidence that the holes had naturally worn a little larger, but no evidence could be found to verify this and measurement with a welder's tip-measuring tool was inconclusive. Yet the technicians knew that the drops varied from day to day, no matter how they tried, because of the many variables involved in producing a beautiful pebble.

The curlers never noticed, and this is the essence of the matter. It is not the shape and size that matters, it is the surface of the pebble, the very tips on top, and if those remain consistent the curlers will be happy. The pebble has to support players and stones for the duration of a game, and if that remains consistent the players will be happy. If the pebble is strong, durable, free of salts, at the right temperature and evenly distributed, a valid starting point has been established from where to develop refinement.

Every morning the pebble has to be removed through cutting, and in the case of Forest Hills the pebble was cut as closely down to the pad as possible. The ice surface would be warmed to – 3.5ºC for cutting, the long walk would begin, and the pebble would be replaced for the day. It soon became clear that it was easy to cut down a double extra-fine pebble, but not so easy to cut down three layers of pebble, and quite difficult to cut down four. When a larger medium pebble was used after flooding, it was very difficult to cut it down quickly. There is definitely a balance to be struck between durability and maintenance, where a smaller pebble is easier to cut down than a large pebble. Other technicians using the small pebbles reported the same.

A large drop under normal conditions will produce a domed shape pebble, almost flat, large in diameter with a flat tip. A small drop will produce a high pebble like half a ball, with a much smaller diameter and a sharp tip. The tip of the large pebble will wear ever larger because of the rapid increase in diameter, while the small pebble will wear more gently with less of an increase in diameter, and therefore less variation in influence on the behaviour of the stones. The small pebble will also offer less resistance to the blade and will require less energy to cut.

With the IcePOD some measurements were taken to establish the height of different pebbles. All the pebbling was done by the same technician at 80 swings in 40 seconds, one layer only, with the water at 30ºC and the ice surface at – 4ºC. For every pebble three readings were taken and averaged to provide the height. The results are below:

Pebble head	Hole size in mm	Height in mm
72 (coarse)	0.65	0.37
74 (medium)	0.55	0.66
76 (fine)	0.50	0.71
77 (extra-fine)	0.45	0.99

The fine head was discovered to be a little scaled and the result can be discarded. For the other three there is a consistent increase in height, with the extra-fine pebble three times as high as the coarse. This proves that, under the correct conditions and properly maintained parameters, the extra-fine will – and does – last longer than any other pebble. Even if it gets a little warm, it will wear flat to a lesser extent than the larger pebbles due to its small diameter, and it will cut off very easily (normally two passes will be sufficient). Where size of pebble is concerned, small is beautiful.

Distribution

To understand what the distribution of pebble has to achieve, it helps to do some calculations. The running band of a stone will typically have a width of somewhere between 5.4mm (when new) and 7mm (matured), with a diameter of around 120mm. This will provide a total possible contact area with the ice surface of between 1525mm² and 1750mm². However, not all of the running band is in contact with the surface of the pebbles at any given time.

From measurements taken of the surface of a double extra-fine pebble, lightly nipped, the contact area of individual pebbles varied from 15-0.5mm² per pebble, with an average of 2.6mm² per pebble.

The total contact area between the pebble surface and the running band was found to be 50mm² or less (a total area of roughly 7x7mm). This means that the weight or mass of the stone, which is 20kg or less, has to be supported by about twenty pebbles at any time, exerting a pressure of about 1kg per pebble. This is the energy, from the mass of the stone, that has the largest effect on how a stone will behave when it passes over the pebbles, and an energy of 1kg on a small area of water at a temperature of – 4ºC is substantial.

Should pebble be added to the layer the equation will change, and should the pebble be nipped more severely – or played flat – the area in contact with the stone will increase and so also change the effect the stone has on the pebble. In fact, the same series of tests showed that a successive nip of the same pebble only increased the contact area by about 10%, yet it caused the stones to draw 25% more.

What the actual distribution should be is very difficult to specify. To start with, not all pebbles will be in contact with the stone, but as play progresses the higher pebbles will be worn down and so bring lower ones into play. A stone with a wider running band, say with 20% more potential contact area, might play very well on 20% fewer pebbles. Stones with a very rough running band will wear pebbles down quicker and so need more to compensate, and often this is achieved by adding a larger pebble on top of or over the finer base pebbles. Only experimentation under control of a given set of parameters can ultimately achieve the optimum number of pebbles for a game in any particular venue. For the extra-fine pebble described above, a distribution of about one pebble per square centimetre has proved ideal for a normal, vigorous game. On occasion fewer pebbles were applied (120 swings in 80 seconds, or 75% of the full pebble) simply to see the effect and the curlers never noticed, but under vigorous conditions this quantity of pebble proved inadequate towards the end of the game.

Through these studies it became convincingly clear that even distribution and consistent pebble are both vital, if stones should be expected to behave consistently during a game. Also, considering that the stones in a curling rink are probably the only constant factor, it becomes possible to make the ice constant too, providing that the target parameters are determined and achieved on a daily basis.

Nipping and racking

Because the pebbles are not all the same height when play begins, the stones have to struggle along over the higher pebbles until these are worn or, more likely, broken down. The first end or two will be sluggish and not much fun, until the pebbles are levelled and normal play can begin. To speed up the process the practice of racking, or "running the stones", was introduced, where a number of stones are pushed or dragged over the pebbles within a frame or rack in a systematic pattern so that all the pebbles are addressed, often in opposite directions, to provide the normal playing surface from the first played stone. Of course this will leave the pad littered with fragments of broken pebble, which then has to be mopped up to avoid causing unnecessary interference.

The next development was the Nipper. This instrument, which has three very sharp blades that can be precisely adjusted, lightly shaves the tips of the highest pebbles to level the surface, and even has a trailing mop to collect the debris. It requires less time and effort and provides a very superior result, but is not without its disadvantages. When nipping started the powered cutter was used, without its weights and with the blade at a very shallow slant, and it was a risky business for several reasons.

To nip at all calls for a very level ice pad and very even pebble. The blade has to be sharp and true with very even pressure, and adjustment must be carefully determined. Nip too much and the stones will draw too much due to the increased contact area; nip unevenly and the stones will snake. The Nipper overcomes most of these problems and, once adjusted, will produce a very consistent surface, provided the pad is level and the pebble consistent. The main advantage of nipping over racking is that the pebble is not damaged and the body remains to do its work through the game.

Should the ice pad or the pebble be uneven in any way, it is far safer to rack, or simply to play the surface into shape. The stones will follow the undulations and do very little further damage, and because there is a certain amount of leeway in the level the uneven surface will remain less obvious than it would be after nipping.

Wear of the surface

Having gone to all the trouble of producing a level ice pad covered in a beautiful, consistent pebble, it can be demoralising to see what the curlers do to it. The teflon under their feet cuts the surface down every time they slide along, especially when the shoes are new. The aggressive fibre on their pads scrubs at the surface as hard as they possibly can, in the hope that they can keep the stone straight and make it go that extra bit further. Let's not mention the hands and knees, that melt holes in the surface after as little as a few seconds, and the holes will be there until some conscientious ice technician finds the time to fill them in with water and cut the surface level again. And then of course there are the stones, often roughened with sand paper for extra friction, that will eat away at the pebble with every delivery. These are the tests of any pebble and very much the name of the ice-making game, and the better the curlers are educated, the less damage will be done. There is not much more a curling-ice technician can do but stand aside and watch them play.

What the curling-ice technician must learn to do is to control what he can. Should the surface be too warm the pebbles will wear faster, the stones will affect it more and the ice will melt quicker. Should the surface become too cold there will be more frost, the sweeping will be even harder and it will be a different game, often a ruined game. Wear of the surface is part of the game, but controlling the temperature of the ice surface is the responsibility of every curling-ice technician. It is ultimately the greatest challenge and the highest test of his ability.

The relationship between pebble and stone

See the report on *Why do curling stones curl*.

The future

The knowledge of curling ice has grown in massive leaps during the past few years alone, and much of the learning to understand the science involved can take many years to work through. Simply learning the basics can seem daunting, while new experiments will almost certainly be dependent on better measurement of the small changes involved. If a facility can be constructed within which the environment will be totally controlled, fitted with all the latest monitoring equipment and computer technology, it might be possible to solve the remaining problems and, inevitably, discover many new ones to be researched. Perhaps the most interesting phenomenon already receiving attention is continuous extraction, which is where surplus heat is extracted at the same rate at which it is introduced. Already it has been found that ice as warm as – 3ºC will last for a game, provided the compressor(s) run continuously and extract sufficient heat to keep the ice surface at the same temperature. This enables the surface to behave consistently, or as consistently as can be achieved, and makes for a very fine game of curling. With modern stepped or screw-type compressors, and careful control of the secondary refrigeration system, this should not be too difficult to achieve, but it is not yet clear if the advantages significantly outweigh the disadvantages. Of course, without careful attention to all the other aspects of pebble already examined and understood, continuous extraction could be a dangerous waste of time.

Readers of this report are invited to comment in any way they wish, and also to contribute freely should they have knowledge that is not included here.

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