Scottish Curling-Ice Group

WHY DO CURLING STONES CURL

The study of why curling stones curl is not new. Many theories have been suggested by highly qualified individuals and many have been flawed, while others have looked at certain aspects of physics without even knowing about other factors that could be involved. In science it is said that a beautiful theory is often ruined by one single awkward fact, and here this is certainly the case.
As a starting point, it would be wise to consider all known aspects of the stones, the ice and the environment, that could have an influence on curl. Then perhaps the theories might make more sense.

Factors involved

<u>Weight</u>

The Rules of the Game say that a curling stone, with its handle and bolt (and now perhaps the contents of the handle as well), should not weigh more than 19.96 kilograms. Theoretically this means that a stone needs only to weigh 1 gram to be a stone, while in practice stones will only become lighter due to wear and refurbishment. As mass and energy are equivalent and interconvertible in physics, it is clear that stones weighing less will behave differently. Delivering a stone of 10kg down the length of a sheet of ice takes more effort from the player than one of 20kg because it loses its momentum sooner, and with less mass it should also curl less, depending on the many other influences. The same will apply to a stone weighing 19kg, though to a lesser degree.

<u>Momentum</u>

This is the quantity of motion in the stone, measured by the product of its mass and velocity. This will therefore be related to its mass, with a heavier stone able to travel further than a lighter stone under the same conditions. Therefore the parabola of its curl will be different, as well as its influence on the ice surface as it slows down or loses momentum.
A normal stone of 20kg will curl less at high velocity and progressively more at slower velocities. The more momentum, the less curl.

<u>Rotation</u>

For a stone to curl at all it needs to rotate. As Mark Denny describes it in his papers (NRC Canada), the stone needs angular velocity. His observations are below:

1. The rock veers to the (left) right if given a (counter) clockwise initial angular velocity, and follows a straight line if given no initial angular velocity, on flat ice.
2. The normalised angular speed (i.e., angular speed divided by its initial value) slows down less rapidly than does normalised linear speed, except at the end of the trajectory.
3. Rotational and translational motion stop at about the same time.
4. For conventional angular velocities, the trajectories are insensitive to initial angular speed.

Here “conventional angular velocities" are those normally imparted during a game of curling, and are such that the rock undergoes 1–4 full rotations before coming to a halt.

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In other words, as all curlers know, if a stone has no handle it will stay straight, until it finds a minute obstruction that will make it turn and curl, usually the wrong way. Put too much handle on and it becomes a spinner, also staying straight, and the ideal amount is about two full turns from delivery to where it stops near the teeline. Turn it clockwise and it curls to the right, and anticlockwise for curl to the left.

<u>Friction</u>

Friction is the result of a stone's mass in contact with the ice. Lessen the friction and the stone will travel further and curl less, increase the friction and the stone will travel less and curl more. A heavy stone will have more friction and a lighter stone will have less. The higher energy required to deliver a lighter stone of 10kg down the length of a sheet is to provide it with sufficient momentum to travel the distance, not to overcome more friction, although other factors are also involved here.

Surface texture of the running band

The running band is that part of the stone in contact with the ice. It is in the shape of a ring with the centre hollow, which typically will have a diameter of about 10cm. The width of the band will vary from about 5.4mm when new to as much as 8mm or more when well matured. The texture of this band is the most significant aspect of the stone's behaviour on ice, and it is said that it could have 80% of the say on how a stone will behave. With such a high percentage of influence it is hardly surprising that stone experts or manufacturers are extremely reluctant to give their secrets away, and very little reliable information is publicly available.
A new stone will have a texture decided by the manufacturer. Because the running band will be narrow, the texture will be rougher to provide more friction. A running band that has been allowed to naturally mature through normal play will gradually lose that texture and become quite smooth or seemingly so, and it will also gradually widen and naturally pit. The curl of a naturally matured stone is more predictable and even than that of an artificially matured stone, with the latter tending to curl excessively at the finish.
When a stone is not curling to satisfaction, it has become commonplace for some technicians to resort to "sanding", by using sandpaper to change the texture of the running band. This is an extremely dangerous activity because, should a mistake be made, it can ruin an entire set of stones, with a resulting cost of many thousands of pounds to rectify the problems through proper refurbishment. This should certainly be left to the experts.
Any running band will have a texture. Whether this is as provided when new or from scratches and striations during normal play, there will be irregularities in contact with the ice that, at its worst, will grind away at the ice surface and, at best, will lightly scrape at it. In the process ice will collect in the texture of the stone and freeze into the holes and scratches, gradually causing it to behave smoother, with a higher contact area and less friction. As the temperature of the running band is the same as that of the ice surface and because the ice is very difficult to see, it is very difficult to know what quantity of ice is involved here, and it is equally difficult to measure the effect this has on the stone's behaviour. What is however sure is that a naturally matured running band is the preferred option to a roughened texture.

Profile of the running edge

This too is something of a secret well protected by manufacturers. This is the shape of the edges of the running band, both outer and inner, that will be constructed either to be sharp and so bite the ice, or gradual and smooth to ride the bumps of the pebbles. Like the surface texture of the running band the edges will gradually wear smooth and naturally mature.
Looking at random stones that have run over the length of the ice a few times, some ice will usually be seen collected on the running edges where they are sharp. Sometimes this could be on the outer edge and sometimes on the inner edge. There is no reliable information available as to which is better, and it is virtually impossible to determine if this affects the stones as they appear to play the same. That the sharpness or smoothness of the edges will affect the behaviour of the curling stone is however certain.

Area of the running band

The weight of the stone is distributed through the running band onto the pebble with which it is in contact. If there are twenty pebbles in contact with the stone each pebble will have to bear 1kg, while forty pebbles will only have to bear 0.5kg each. The stone therefore becomes "lighter", relative to the pebbles. This leads to one of the anomalies of a curling stone's behaviour because, although there is less friction on forty pebbles, the stone will draw more due to the larger contact area.
A stone with a wide running band could have twice the contact area than a stone with a running band of 5.4mm and the result will be much the same. Should the texture and profile of the running band be constant, the pebble will have to be adapted in order to achieve the desired amount of curl and speed. Usually most technicians are able to find the ideal for their particular stones and environment, which they then proclaim as gospel – in reality a certain set of stones will behave much the same in any other rink because nothing about the stone has changed, least of all the surface area.

Area of ice surface

It is possible to map the contact area of pebble with carbonised paper. Scan this onto a computer and use a program to calculate the area in contact with an imposed profile of a stone's running band. This method reveals that the area is only about $0.5 cm^2$ on fresh pebble, rising by about 40% during the game. It also reveals that a very light nip will increase the contact area by about 25% to speed up the process, so allowing the stones to play normally from the start. A small pebble will enlarge less during a game because the contact area will not increase dramatically under normal temperatures, while a large pebble will acquire a larger contact area more quickly, due to the difference in size.

Temperature of the ice surface

The ice-surface temperature (IST) is one of the most important factors when considering a stone's behaviour as it slides over the surface. For clean water, i.e. an ice pad with virtually no salt content and pebble water that has been deionised or cleaned in some other way, the ideal IST has been established as – 4.5ºC. Should there be some salts in the water the IST will be warmer and more heat will need to be extracted by the refrigeration plant to achieve – 4.5ºC. During play additional heat introduced into the rink will also need to be extracted to maintain the IST, which can rise to as warm as – 3.8ºC or more before play is badly affected. Condensation of moisture in the air onto the ice surface will also raise the IST, while evaporation from the ice surface will lower the IST. Turbulence will move additional heat from the air onto the ice surface, and the speed with which this is extracted can change the nature of the ice surface significantly.
Should the IST rise to above – 3.8ºC the ice will be softer and more easily damaged by curlers and stones, thereby going "flat", where the pebble visibly wears away. Even before that stage the bonding between stone and pebble can be accelerated to create increased draw, while the same bonding can create drag on a stone's momentum and slow it down considerably. It is imperative that the IST should remain cold enough to support the stone consistently during a game of two hours or more.
Should the IST be too cold there could be less bonding between stone and pebble, causing the stones to play straighter and faster. Of course there are other factors involved too, such as frost, stone texture and heat transfer, but an ice surface colder than – 5ºC will behave very differently to one at – 4ºC. Maintaining the most suitable IST in a given curling rink is one of the greatest challenges facing the ice technician. Because of the very many influences at work there are no golden rules, and only knowledge, experience, observation and experimentation will ultimately find the correct balance.

Temperature of the stone

This might seem obvious, but if the base of the stone is not at the same temperature or colder than the ice surface it will affect the ice to create increased bonding. This could be so bad that the stone literally melts into the ice, or so little that it is ignored. Simply cleaning the stone vigorously with a brush or pad will warm its surface and cause it to play slower, while cleaning it with a warm hand will aggravate the problem. The temperature of the running band should be kept the same as the IST for the stone to behave normally.

Temperature of the air

The roof temperature (RT) just under the ceiling and the air temperature (AT) at 1.5m above the ice surface are both very important, and are excellent indicators of what might happen in the next hour or two within the rink. In colder countries the RT could be below 0ºC where no heating is provided, while in a full arena it could well exceed 30ºC. Because warm air holds significantly more moisture than cold air the humidity in a warm rink will be higher and, if the excess moisture is not extracted, it will condense and freeze onto the ice surface. It could even become so high that it will condense onto any surface colder than the dewpoint, causing drips from the roof and running water down the walls. Reduce the heat in the roof space and the moisture will have to be extracted, or the ice surface will very quickly be covered by a blanket of fog and frost from condensation.
The air temperature is easier to measure because it is within easy reach, and usually this will be maintained around 7ºC. If sufficient moisture can be extracted this will establish a dewpoint temperature (DPT) below 0ºC, a stage at which the frost will not adversely affect a game of curling. The ideal is said to be a DPT of – 4.5ºC to equal the IST, where there will be no frost, while anything warmer will lead to the formation of a microscopically thin layer of amorphous (non-crystalline) ice on the ice surface. This layer of amorphous ice is in fact frost, present but unseen when thin, and could be a very important factor in the behaviour of stones. It is the combination of RT, AT, DPT, IST and humidity that will dictate the thickness of the frost, and if the temperatures and humidity are not carefully controlled the problem can easily grow beyond control.

Frost (amorphous ice) on the ice surface

Moisture in the air will naturally migrate to the drier environment, here closer to the ice surface. If there is a surplus at this colder temperature it will condense into fog, and the fog will further condense into frost on the ice surface, or the moisture can condense directly into frost. Because condensation releases energy as heat, any of these will heat the ice surface. On the other hand some of this condensation can evaporate or the ice surface can sublimate, absorbing heat. It is a near-continuous process and, should the DPT be higher than the IST, will lead to the formation of amorphous ice on the ice surface and of course the tops of the pebble. Because this non-crystalline ice is easier to melt, however partially, than the solid ice beneath, it will have the most reaction to a stone sliding over it.

Humidity

Every curling rink will contain water vapour in the air to a certain degree. Some will have too much and others too little, and over a period of time problems can accumulate sufficiently to affect the ice surface. The actual moisture content can be calculated from an IX-diagram, if the air temperature and relative humidity (RH) are known. For instance, with an AT of 10ºC and RH of 40%, the moisture content is 3 grams of water per kilogram of air (g/kg). With an AT of 10ºC and RH of 80%, the moisture content is 6g/kg, double the amount. With an AT of 5ºC and RH of 40% the moisture content is 2.1g/kg. In the first scenario the DPT will be – 2.6ºC, not too high and low enough not to affect the ice surface much. In the second scenario the DPT will be + 6.7ºC, more than 10 degrees above the IST, and frost will be a problem. In the third scenario the DPT will be – 6.6ºC, and the ice will gradually sublimate to supply the air with more moisture.
It is not clear what the ideal scenario is, because of the many influencing factors in different rinks. In *Curling Ice Explained* the parameters are given as an AT of 7-8ºC and an RH of 40-50% for an IST of – 4.5ºC, and these are achievable in most rinks for good curling. In reality, however, variable conditions will soon change the parameters one way or the other and challenge the ice technician. It is certainly the case that many technicians have to achieve the art of the possible and many are extremely good at manipulating one parameter to influence another, when they do not have the equipment to exercise control. For instance, under conditions of high humidity and inadequate dehumidification the heating in the roof space can be reduced, usually overnight, to release the moisture as fog and frost onto the ice surface, which can then be cut off. Switch the heating back on in the morning and the warming air will have a higher capacity to hold moisture, sufficient to keep the technician out of serious trouble for a day or so.

The MSMM/F event

The Mini-Second Micro-Melting and Freezing event occurs as sufficient energy is applied to ice, amorphous or crystalline, to melt it, with the amorphous ice more affected due to a weaker molecular structure of hydrogen bonds, and refreezing occurs almost immediately. A curling stone weighing 20kg has been calculated to release sufficient energy to create a layer of water about a micron thick, first from its momentum as it travels down the ice sheet, then increasingly from its mass as it slows down. It is not yet clear whether this film of water is conducive to aid both its linear and angular velocity by decreasing friction, or whether it increases bonding between stone and ice and so increases friction, or even both. What is clear is that removal of the amorphous ice increases the linear velocity and decreases the angular velocity, and the conclusion can be drawn that, because the crystalline ice is more difficult to melt than the amorphous ice, there is less friction and therefore less bonding between stone and ice.
Consider a real scenario for which figures are available. For a small pebble, lightly nipped, the average surface area per pebble has been calculated as 2.5mm². The total contact area for a running band 6mm wide has been calculated as 0.5cm², or 50mm², which means every pebble has to support 1kg of granite. This is clearly significant. As every curler knows, leave a stone in one place for long and it will melt a sufficient amount of ice to freeze to it. The longer it is left in one place, the deeper it will freeze into the ice, until it actually creates a hole.
A stone travelling down the ice sheet with a slow clockwise turn will create a continuous MSMM/F event by its momentum, initially with very little obvious angular velocity, or draw. The lubrication will help to minimise friction, and the fact that there is little difference in the time both left and right sides of the running band spend on a given set of pebbles will initially give little draw. However, as the stone slows down the right side of the stone will spend longer on the pebbles than the left and increasingly so, thereby able to create a larger MSMM/F event and melting slightly more ice. With the increased opportunity of bonding the stone draws more and more until it loses all its momentum and can often give one final spin before it stops.

<u>Lubrication wedge</u>

The slower a stone moves, the less energy it has to lose, other than its mass. Assuming that it does create a semi-fluid lubricant by MSMM/F this will be adequate to allow smooth passage down the length of the sheet of ice, but when the mass takes over it will only have an effect until the momentum expires. The slower a stone moves, the more bonding time is available to bond crystals to crystals due to increased friction caused by the smaller "lubrication wedge". Sweeping not only removes the amorphous layer, it also partially warms the ice surface to enable better lubrication, helping the stone to travel further and curl less. Perversely it has been observed that heavy sweeping of a slow-moving stone, on pebble as warm as – 3.8ºC, can in fact create excessive lubrication and cause the stone to curl more and stop very suddenly.

<u>Quality of water</u>

There are more rinks using tap water or "raw" water for curling than there are rinks that use clean water. Until recently the use of deionised water had been the reserve of experts, while it is now becoming more common for use as pebble water. In the absence of scientific support, mainly because it is extremely difficult to do tests on water at – 4.5ºC, only the experience of experts can be relied on here. The fact of the matter is that clean water, free of all impurities, will have a different and better bonding of molecules, to ensure a strong and consistent pebble. These pebbles will last longer under the pounding they take, yet be able to allow for the small amount of MSMM/F necessary for good curling.
Anyone who is used to using clean water will confirm that it gives a very different ice than that of tap water. The difference is most obvious when using clean water for a while and then reverting to tap water.

<u>Dust and fibres</u>

A factor often overlooked is that dust from the air, usually very fine and almost impossible to see, will bond to the ice surface, along with small fragments of clothing fibres from the clothing of curlers. The dust will initially become wet by interacting with moisture in the air and then with the amorphous layer, where the hydrogen-bonding network of the water will not release it back into the air. The dust becomes trapped and will increase the friction between the stones and the ice surface. This friction, should the stones not be properly cleaned before every delivery, can cause havoc under certain specific conditions, when the MSMM/F effect allows the dirt to freeze to the stone and accumulate. Within a few ends of curling the curl will become increasingly exaggerated and behaviour of the stones can then only be described as ridiculous.
In the theory below by Mark Denny, the dry ice could also be considered as dust, but what happens to it is best left to science to explain in the extract.
The bonus of this problem is that it serves as the ideal abrasive to allow a stone to gradually become naturally matured after a few years. In days gone by when dirt was more common stones matured a great deal sooner than they do in today's much cleaner environment.

Theories

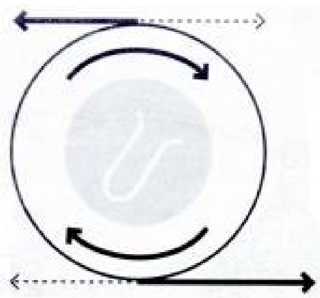
There are many theories in existence, many of them extremely difficult to understand without a full knowledge of physics. Both Mark Denny and Mark Shegelski have obviously spent many years trying to conclusively prove their theories, which paradoxically contradict each other. The essential difference between them is that Denny prefers dry friction, while Shegelski prefers wet friction. Extracts of their theories appear below.

Dr Mark Shegelski

An overturned drinking glass sliding over a smooth surface and rotating clockwise will curl to the left. As the overturned glass slides over the smooth surface, it tends to tip forward. Consequently the front of the glass pushes harder on the surface than the back does. Thus, the friction on the front of the glass is greater than the friction on the back. For a clockwise rotation, the "sideways" motion of the front of the glass is to the right, so the sideways component of the friction on the front of the glass is to the left, and the glass curls to the left.
A curling stone, on the other hand, will curl to the right, opposite to that of the drinking glass. The reason is that the friction on the front of the stone is less than the friction on the back. Part of the explanation is that, like the overturned drinking glass, the curling stone tends to tip forward as it slides down the ice, and so the front exerts a greater pressure on the ice than the back. More pressure on the front means that the front of the stone causes more melting (momentarily) than the back. Consequently, the front of the stone will have less friction than the back. For a clockwise rotating stone, the sideways motion at the back will be to the left, and the friction at the back (which is greater than on the front) will be to the right, so the stone curls to the right. (See diagram below.)

This is not the whole story, or curling stones would not curl nearly as much as they do. The friction on the front is not only less than on the back, it is much less, especially when the stone is slowing down, coming over the hog line and into the Free Guard Zone or the house. This explains why curling stones curl most at the end of their motion. Due to the motion of the stone over the ice, there will be a momentary melting of the ice and the formation of a thin film of liquid just beneath the running surface (contact ring) of the stone. As the stone slides and rotates, the thin contact ring will tend to drag some of the thin liquid film around it as it rotates.
There is a force of attraction between granite and water: water tends to cling to granite. Thus, the thin liquid film under the stone tends to get dragged along with the stone. As the stone slows down, this thin liquid film is dragged around the stone, from the back along the side and eventually to the front. Consequently, the front of the stone will have even less friction on it than the back (as the stone slows down) and that is why most of the curl happens near the end of the stone's travel.
Now consider the motion of a rapidly rotating, slowly sliding curling stone (a "spinner") and the shape of the pattern of contact between the stone and ice. Spin it as fast as possible and push it only slightly, so that the stone is rotating very rapidly and sliding over the ice so slowly that it would only move from one side of the house to the other.
The model predicted that because the stone is sliding so slowly, the contact ring will have ample time to drag some of the liquid film around it. In fact, the liquid would be circling around the stone at an appreciable fraction of its rotational speed. The result is be that the frictional forces will change so that friction will stop the stone sliding long before it stops rotating.

A curling stone therefore curls because (1) melting occurs as the stone slides over the ice, and (2) the stone drags some of the thin liquid film around it as it rotates, making the friction much less at the front than at the back of the stone, especially when it is in its final feet of travel.



In a clockwise rotating stone, the "sideways" motion at the front is to the right (dashed arrow), and the sideways friction on the front is to the left (solid arrow). The sideways motion at the back is to the left, and the friction is to the right. Because the friction at the back is greater than at the front, the stone curls to the left.

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Mark Denny

The snowplow model

This model provides a form for $f(\phi)$. Many models are possible, and their relative merits can only be judged by their internal consistency and by comparing model predictions with observation. Should two models prove equally successful, then more detailed experimentation will be required to separate them. However, we are not yet at this stage; to date there is no generally agreed model that is compatible with observation. The snowplow model will be seen to be a step along that road.

We begin by recalling that the rock is in contact with the ice only at the running band, which is an annulus of mean radius $R = 6.3$ cm. The inner and outer running band radii are $r_1 = 6.0$ cm and $r_2 = 6.6$ cm. (These figures vary slightly from rock to rock.) Also recall that the rock travels over pebbled ice, and so the motion is not really smooth; the rock bumps along over deliberately roughened ice. We shall assume here that this motion causes the ice to chip, or splinter, due to contact with the leading edge of the rock running band. The resulting ice shards or splinters, henceforth referred to as *debris*, litter the ice just in front of the advancing rock (perhaps only a few millimetres in front). The larger particles of this debris will simply be swept aside by the advancing rock — hence the name "snowplow" given to this model. Intermediate-sized particles of debris may find their way underneath the running band, however, and these will influence the friction coefficient between rock and underlying ice. Smaller particles may also end up under the running band, but we do not expect these to influence friction, since they are small compared to the roughness scale of the running band and of the pebbled ice. It is only the intermediate-sized particles of debris that can reasonably be expected to alter the friction coefficient.

We consider that such debris particles become lodged in the running band for a short time, during which the local friction between running band and ice is reduced: it is the friction of ice on ice, rather than of (roughened) granite on ice. This debris beneath the running band is naturally carried to one side as the rock rotates. For a counter-clockwise rotating rock, we expect that more of the debris will accumulate on the left than on the right. We assume that the debris is pressed against the running band, owing to the weight of the rock, and sticks to it, until it is carried around the rock a short angular distance of perhaps half a rotation. The debris is then dislodged, or more likely it melts due to frictional heating, or is worn down. Thus the debris reduces friction asymmetrically, until it is carried around to some critical angle ϕ_0, where it is dislodged, or melted, so that it no longer contributes to reduced friction.

We may briefly summarize the consequences of snowplow model assumptions as follows. There is reduced friction at the front and on the left side of a counter-clockwise rotating rock, because of debris movement around the running band. The left–right asymmetry increases with rock rotation until the rock has rotated a critical angle ϕ_0: thereafter the asymmetry is constant. ϕ_0 is expected to increase as initial angular speed increases.

It would be remiss of us to merely state the snowplow model hypotheses, however reasonable they may appear. So, we present some evidence that lend support to our assumptions, as follows.

Firstly, we have said that the rock "bumps along" the ice, and does not glide smoothly. This is what gives rise to the debris. What evidence is there for this? Anyone who has *listened* to a curling rock advancing along the ice will testify that its progress is not a smooth glide: the rock growls as it moves. This noise indicates a bumpy progression. Also, lightly touching a moving rock (not allowed in a game of curling, but permissible for investigating physicists) reveals a level of vibration that again suggests bumpy motion.

Secondly, we have consulted a leading curling rock manufacturer who considers the *cutting angle* of the running band to be an important factor influencing rock motion. Cutting angle measures the steepness of the slope of the running band. Were smooth friction solely responsible for determining rock motion, then cutting angle would have no influence at all, since it refers to parts of the rock that are above the ice surface. However, it will certainly come into play in the snowplow model, since it will undoubtedly influence the rate of ice chipping and perhaps the size of debris particles produced. A rock that has just completed a trajectory can be seen to have gathered debris along the running band; the curler sweeps this off before the rock is used again. So we know that debris is generated by the rock and that it accumulates under the running band.

Thus, we consider that our snowplow model assumptions are plausible. The form of $f(\phi)$ that is implied by this model is, assuming dry and not fluid friction.

Sweeping

It is appropriate here to address the influence of sweeping upon curling rock motion. Sweeping has the effect of increasing the length of the rock trajectory and of decreasing the curl distance. These effects have been assumed to be due to ice melting and producing a lubricating layer. However, calculations also show that sweeping produces only a thin layer of melt-water. Assuming that all the mechanical energy of the sweepers is converted into heat that melts the ice, it can be shown that the layer of water produced is only a few microns thick. This layer will either refreeze prior to contact with the rock or it will flow down from the pebble peaks and so is not likely to be in contact with the rock. Indeed, this is a problem for all theories of curling rock motion that rely upon a liquid layer: how can the layer *support* the rock, given that the underlying ice is pebbled? It was shown that it cannot do so. Anyway, it is not necessary to invoke ice melting to explain the effects of sweeping. We need only note that sweeping causes the ice temperature to increase, and that the coefficient of ice friction falls quickly as ice temperature approaches the melting point, due to softening. This is a much more likely explanation of the effects of sweeping, since raising ice temperature requires much less energy than melting ice, given that the latent heat of fusion is so high.

What these theories do illustrate is the complexity of the processes involved. Careful analysis of all the factors only conclude that none of these can be dismissed as invalid, and the same must be said for these two theories, as well as most other theories. For those who wish to study these theories in detail, they can be found on the website of the National Research Council (NRC) Canada. Search for curling in the Canadian Journal of Physics, which will then display a list of the matching documents.

Conclusions

It is probably best to assume that all the above is relevant, though in varying degrees according to varying parameters. For instance, in a humid environment with the DPT higher (warmer) than the IST, amorphous ice or frost will play a very important role. On the other hand in a colder and drier environment, with the DPT lower (colder) than the IST, the texture of the running band and/or the shape of the running edges will become more significant. This could well explain why the stones are sanded quite often in colder countries, but seldom in warmer countries like Scotland. Humidity alone can be a huge factor if it is too high or too low, and temperatures will always be important.
The parameters given in *Curling Ice Explained* were defined as a starting point that gives a curling-ice technician something to aim at, even in a strange arena. These have been tested in many curling rinks and have been found to be valid and useful. Until the same standards of uniformity are established for curling stones, the texture of the running bands and profiles of the running edges, it will be extremely difficult to say that any one theory is accurate or even valid. Until then all the above will come into play and clear definition remains a matter of interpretation.

John Minnaar
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