

Building for the Future

Innovative warehouse design for efficient maturation of Scotch whisky

By John Conner and Andrew Forrester

The 'Angels' Share' in Scotch whisky production accounts for an average annual loss of two percent of all maturing stocks. This is a considerable financial loss to the industry and also has implications for production and resource efficiency. Dr John Conner and Dr Andrew Forrester of the Scotch Whisky Research Institute, describe the MATIN Project (Maturation Innovation), which examined how the design and construction of a maturation warehouses affects the internal environment – and how this in turn influences how much whisky is lost from the cask. The work was carried in collaboration with The Building Research Establishment (BRE).

Scotch whisky must, by law, be matured in an oak cask in Scotland for a minimum of three years. During the maturation, a considerable amount of spirit is lost from the cask and represents a significant financial loss to the distiller. This is not just lost revenue, but also the raw materials and energy required to make this 'Angels' Share'.

The amount of spirit lost varies with cask size, but a typical cask is estimated to lose approximately 2% of its ethanol per annum. Based on an average bottling age of six years, this is a total loss of 14 litres of ethanol from a barrel of approximately 190 litres. The loss is much greater for premium products, such as single malts. Not only is the value of the lost whisky greater, the typically longer maturation results in higher losses.

Figure 1 represents typical losses from a warehouse for six and 12-year-old whiskies. After 12 years, 22% of the original new make spirit has been lost from the cask. Not surprisingly, many distillers have considered ways to reduce this level of loss but none have entered common use as they have been unable to effectively reduce losses without impacting on quality.

The warehouse influences how much the angels get

The amount of spirit lost is determined, at least in part, by the environmental conditions experienced by the cask. This is influenced, in turn, by the design, construction and location of the warehouse. The impact of location is most obvious when comparing across national boundaries.

For example, the rate of loss in Kentucky, USA is nearly twice that in Scotland. Climate is undoubtedly a crucial factor, with annual average temperatures 5-6°C higher in Kentucky. However, there are also significant differences in the design and construction of warehouses between the two locations that influence the internal environment.

A variety of warehouse designs are in use today in Scotland and our earlier studies have shown differences in their internal environments. However, we were previously unable to relate these differences to the design or construction of an individual warehouse.

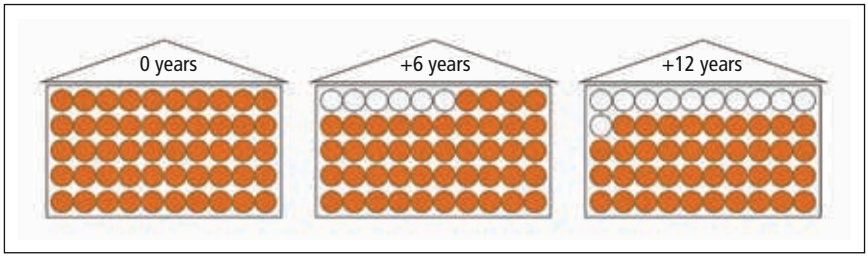


Figure 1: Typical losses from a warehouse over six and 12 years

Not all warehouses are the same

The earliest 'dunnage' warehouses were typically heavyweight buildings with slate roofs and thick stone walls. The amount of stock stored in these warehouses relative to their size was small, limited by the low roofs and traditional three-tier racking systems used.

The next major phase of warehouse building coincided with the 1960s/70s boom in whisky consumption and production. These buildings were typically concrete or brick-built with asbestos roofs and were much larger, holding significantly more stock, typically in racks up to 12 tiers high. More recently warehouses have been steel framed and used corrugated metal panels for both roof and walls.

Stock in these warehouses is typically palletised and densely packed with little space left between stacks, further increasing the density of the stock held in the warehouse. All three types of warehouse, and variations on each theme, are still in use across Scotland.

Developing a comprehensive understanding of the warehouse environment

The earliest warehouse studies recorded the environmental conditions and how these changed throughout the year – but were unable to relate differences to the design and construction of particular warehouses. This was partly due to the limitations of the equipment available at the time.

For example, temperatures were recorded on a weekly basis using minimum/maximum thermometers and humidity represented by a single weekly measurement. The development of intrinsically-safe temperature and humidity loggers has allowed us to collect hourly measurements giving far greater insights into daily variations in environmental conditions.

Even with this greater detail, working out how each element of the warehouse location, construction and content influence the internal environment is still a complex problem. For the MATIN project we monitored 17 warehouses around Scotland and in no two warehouses could differences in the internal environment be related to a single design feature.

The solution was to develop a building energy model for maturation warehouses. Two warehouses were intensively monitored with up to 36 loggers recording temperature and humidity in different parts of the warehouse. BRE used this data to calibrate computer models for each warehouse that allowed the accurate prediction of the internal environment from external weather files for the location.

This calibration was necessary to account for the unique features of maturation warehouses such as the levels of maturing stock inside and amount of ventilation.



Construction of a modern warehouse (Tamdhu Distillery/Ian McLeod Distillers Ltd.)

Cask storage systems, old and new



Early 'dunnage' racking



More recent densely-packed palletised casks



1960s/70's racked warehouse

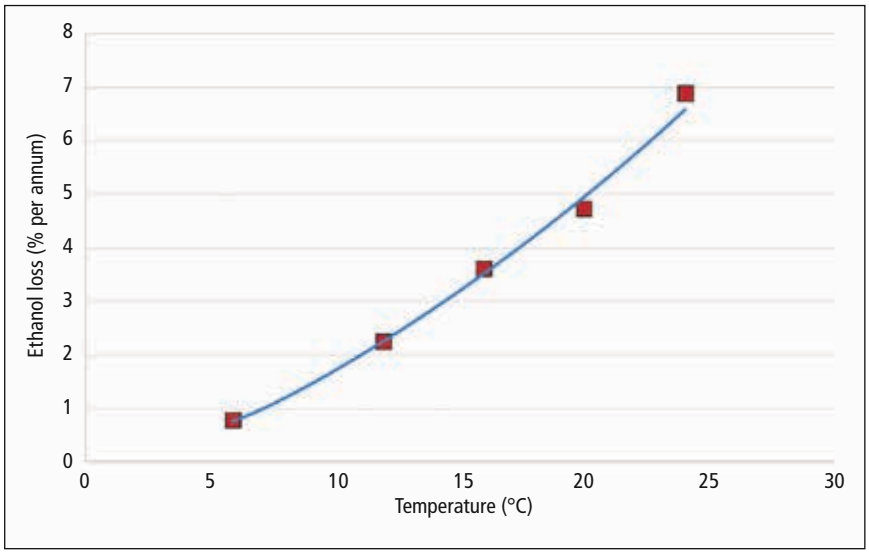


Figure 2: Relationship between temperature and losses



Casks in the SWRI controlled environment store

The MATIN project allows warehouses to be designed to minimise losses

BRE used the knowledge gained from the calibration process to develop a model for a 'typical' maturation warehouse. This was used to show how changes in, for example roofing materials or insulation level, altered the internal environment.

Many scenarios were tested using the model to assess the impact of current and future construction options. Based on this, BRE have created an on-line tool to explore refurbishment options for existing warehouses and produced a set of guidelines for building new warehouses.

Using the building energy model, BRE could accurately relate changes in construction to the internal environment of the warehouse. Another important part of the project was to find out how these changes influenced the rate of loss during maturation. Our previous research had shown that humidity affected bulk volume and strength changes during maturation but did not directly impact on the loss of ethanol.

For the MATIN project we focused on the two remaining features that we thought were likely to have an impact, warehouse temperature and air flow.

In experiments carried out at SWRI, we found that temperature was the major determinant of losses. Figure 2 shows the results of trials relating temperature and losses. In a controlled environment, more than 98% of the variation in average losses could be attributed to temperature.

In contrast, BRE's trials comparing different air change rates showed no significant difference in losses at two temperatures, indicating that within normal ranges ventilation did not directly impact on ethanol loss.

To test whether the relationship developed under controlled environmental conditions could be used to predict losses from industry warehouses, we measured losses from 153 casks distributed across a variety of different warehouse environments. This included the top and bottom tiers of warehouses and at various locations in the north and south of Scotland.

Figures 3 and 4 show average daily temperatures over two years for warehouses in north and south Scotland respectively. Annual average temperatures were 10.2°C and 8.7°C respectively. However, the situation is more nuanced. For example, we found the smallest differences in temperatures for top tiers during the summer months (average 0.9°C difference in July) and largest differences for bottom tiers in winter (average 2.6°C difference in January).

Based on the temperature profiles, we would predict that the difference in losses between the two warehouses would be 0.3 to 0.4% ethanol per annum, with similar differences for the top tiers (2.1% per vs 1.8 % ethanol per annum) and for the bottom tiers (1.8% vs 1.4% ethanol per annum). In reality, the losses from individual casks varied widely.

For example, for hogsheads, the cask size used for the SWRI trials, industry losses varied from 1.6 to 4.7% ethanol per annum, not including two leaking casks that lost 8.4 and 9.0% ethanol per annum.

This large variation suggests that losses in industry warehouses would be better represented by a range rather than a single average value. To achieve this, we developed separate relationships between temperature and loss for casks with the lowest, the average and the highest losses in the controlled environmental studies. This allowed us to estimate a range of losses based on our warehouse temperature data. We found that in industrial warehouses most casks performed between casks with average and highest losses in the SWRI trials.

One reason for developing the relationship between temperature and losses is to be able to quantify the amount of ethanol saved per annum and allow a cost-benefit analysis of any changes to warehouse design to be made. This analysis was based on casks with average losses. However, we discovered that losses in most industry warehouses are greater than this. The average losses are therefore a conservative estimate of the savings derived from changing warehouse design.

Losses vs Quality: The MATIN project allows distillers to make informed choices

We found that temperature was the major influence on spirit loss and therefore any design feature that lowered temperatures within the warehouse would reduce losses. However, reducing the temperature could also reduce the rate at which the whisky matures. This means that longer maturation is needed to achieve the required quality and this in turn would accrue additional losses.

To address this, we carried out a series of experiments to show how temperature influenced the different maturation reactions: extraction, adsorption/degradation by cask char and

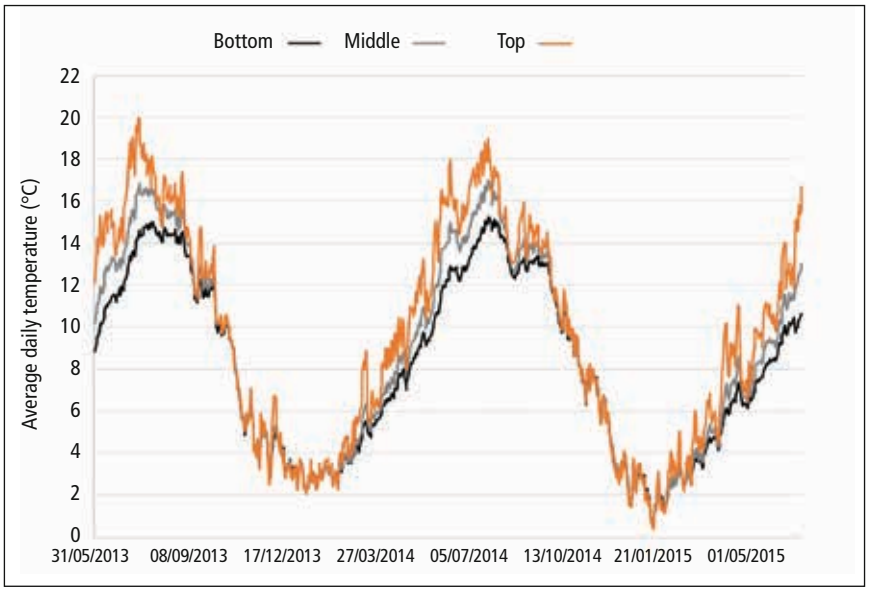


Figure 3: Average daily temperatures for a warehouse in north Scotland

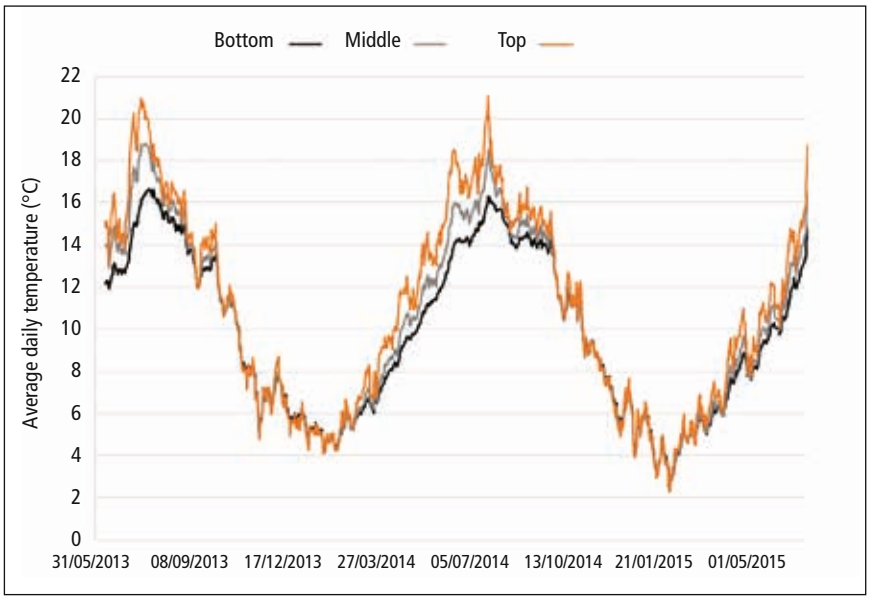


Figure 4: Average daily temperatures for a warehouse in south Scotland

the transformation of extractives. Our results show that higher temperatures result in faster extraction of colour and more colour.

Figure 5 shows the relationship between extraction temperature and colour development for wood flour, while similar experiments showed a quicker reduction in sulphides by cask char and a faster transformation rate of cask extractives dissolved in spirit.

Consequently, any changes in warehouse design must balance reduced losses with its impact on maturation quality. This can be illustrated by comparing colour development (a good marker for maturation quality) in casks in the north and south warehouses that we monitored (see above). Remember that losses varied between 1.4 and 2.1%, depending on warehouse location and position of the cask in the warehouse.

Using our data, we estimate that the same cask in the north warehouse would develop colour levels 13% lower than the south warehouse. Based on the temperature profiles that we observed, this would also vary with position within the warehouse.

The smallest colour difference would be observed if the casks were stored on the bottom tiers (approximately 9% lower) and largest if stored in the top tiers of the warehouse (about 20% lower).

Building the ideal maturation warehouse

The previous example illustrates the trade-off whisky producers must make between losses and quality. Consequently, the design of the ideal maturation warehouse will depend on the distillers' priorities. In some cases, minimising losses may be of greatest importance whereas in others product quality may take priority.

The MATIN project allows distillers to consider design and construction of warehouses in a scientific manner and make decisions based on a robust cost-benefit analysis.

The location of warehouses, however, is often out of the distiller's control, but is an important factor in determining the internal environment. Making accurate predictions of conditions within a specific warehouse design requires a detailed weather file for the location but these are not always available for warehousing sites. Using the data collected during the project we developed relationships that can estimate average monthly temperatures within the warehouse from its latitude and altitude.

These estimates are most accurate for the winter months and least accurate for the top tiers during the summer months, as it is during the summer months that the design of the warehouse has most influence on the internal environment. Either way, the models that we developed provide additional information to support decision making when siting warehouses.

The modelling work carried out by BRE provides an understanding of how different construction elements, singly or in combination, influence the internal environment. This shows that for a large warehouse, some design features have only a limited impact on the internal environment. Surprisingly, this includes whether the building is of lightweight construction (e.g. using sheet metal) or heavyweight construction (with masonry or concrete walls).

A crucial factor however, is the thermal mass of the maturing whisky, which takes time to heat up and cool down regardless of the building type. This is not to say the building has no impact and anything that reduces the rate of energy transfer into the building during spring and summer will give lower summer maximum temperatures and losses.

On the other hand, design features that increase the rate of energy transfer will raise summer temperatures and losses. While losses are at their peak in summer, they continue throughout the year and design fea-

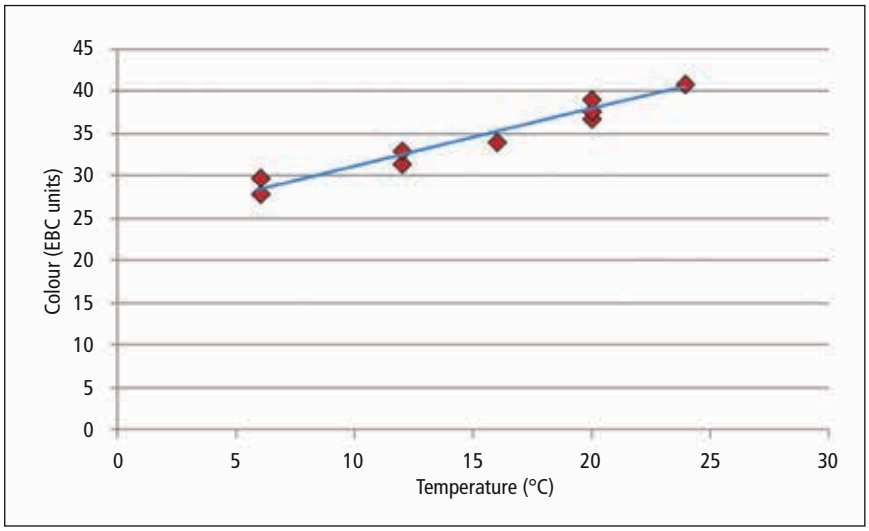


Figure 5: The relationship between extraction temperature and colour development for wood flour

tures that have one effect in summer may have the opposite effect in winter.

An example of this is insulation. This slows the transfer of energy into the building during spring and reduces maximum spring temperature for all tiers. However, it also reduces the rate at which energy is lost during the autumn and winter, resulting in higher temperatures and losses during the winter months.

Figure 6 illustrates the impact, using the on-line refurbishment tool to compare temperatures and losses between a steel-framed sheet metal warehouse without insulation and one with insulated walls and roof. This estimated the annual average temperature of the insulated warehouse to be 0.08°C warmer than the un-insulated warehouse. Broken down for seasons, spring temperatures were 0.5°C cooler in the insulated warehouse but autumn and winter were 0.4°C and 0.5°C warmer respectively.

The overall impact was a small reduction in losses (0.02% ethanol per annum) due to the insulation. This is true of many potential adaptations, with reductions in losses over spring and summer being partly cancelled out by increased losses during the winter. This makes it difficult to make substantial reductions in losses through building design.

Of equal importance, the project has helped to identify design features that singly or combined would increase losses. These are features that increase the flow of energy into the warehouse during spring and summer, without necessarily increasing the rate of loss of heat during autumn or winter.

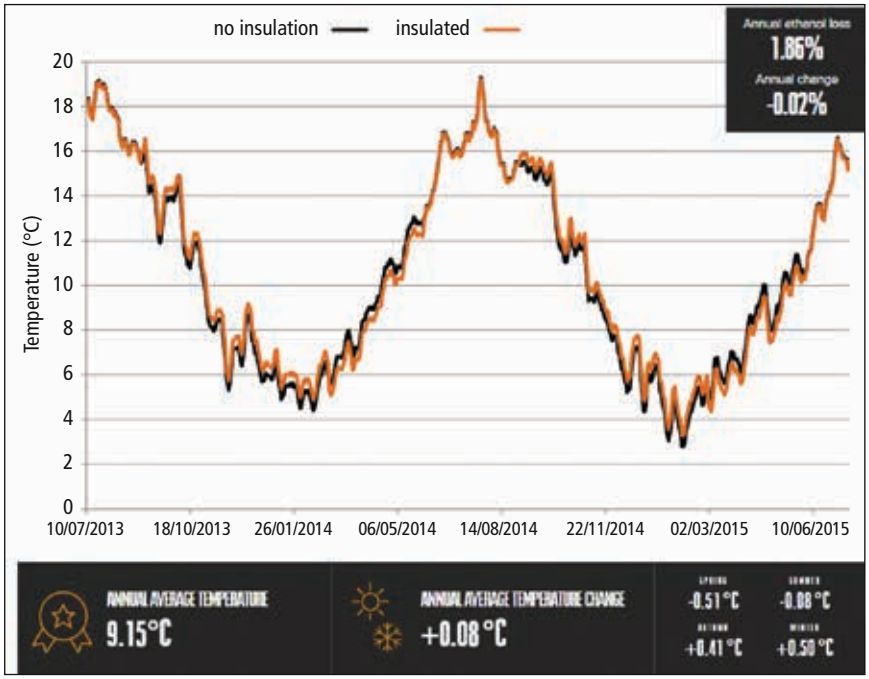


Figure 6: Comparison of metal warehouses with and without insulation

Using our models, we estimate that a typical new-build warehouse would have average annual losses of approximately 1.78% ethanol per annum. Optimising the building design could reduce this by a small amount to 1.74% ethanol per annum. However, incorporating the wrong features into the warehouse design could result in estimated losses of 1.92% ethanol per annum.

Building for the future

Successful maturation is about achieving the right balance and this is as true for the warehouse environment as it is for any other aspect. In the design of a warehouse distillers must achieve a balance between losses and quality. Through the MATIN project, the combined expertise of BRE and SWRI has created a new understanding of the warehouse environment that allows distillers to take a scientific approach to this balance and consider the costs and benefits of different design features.

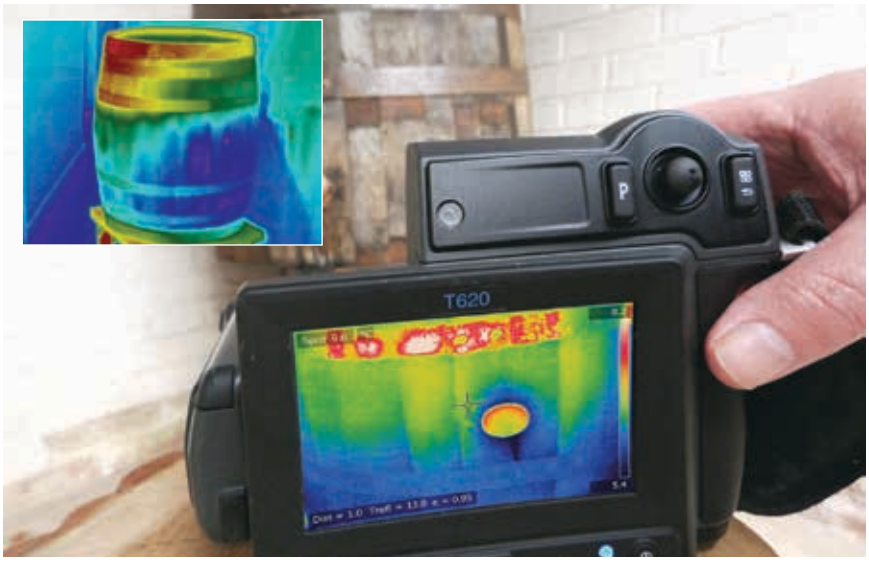
One concern of distillers before the project was that the changing design of maturation warehouses was having an unknown impact on losses during maturation and product quality. Our findings suggest that while current designs are not the optimal for losses, provided certain combinations of features are avoided, they are not giving rise to excessive losses during maturation.

Again, the dual focus on losses and quality allows consideration of the impact on both factors for any future changes in warehouse design.

Finally, our research for the MATIN project used losses from a small set of casks as a yardstick for comparing losses in different warehouse environments. Monitoring larger numbers of casks in industry warehouses showed a broad range of losses from individual casks and suggests that, in addition to warehouse temperature, cask integrity is also an important consideration for losses. Key factors that influence cask integrity are a major focus of current maturation research by SWRI.

About the project partners

SWRI is a privately-owned Research & Technology Organisation (RTO) dedicated to the needs of the Scotch whisky industry. It carries



Using an infra-red camera to detect leaks in casks

out a comprehensive programme of pre-competitive research across the entire production process and provides consultancy and analytical services to its member distilling companies.

BRE is the RTO for the building and construction industry. It is an independent research-based consultancy, testing and training organisation, offering expertise in every aspect of the built environment and associated industries. BRE provides expert, impartial research, knowledge and advice and helps government, industry and business in creating better, safer and more sustainable products, buildings, communities and businesses and support the innovation needed to achieve this.

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John Conner is a senior scientist at SWRI and leads the maturation research group.



Andrew Forrester is the Technology Transfer Manager at SWRI.

John Freeman, Mark Patterson and Peter Cockburn of SWRI contributed to the work on losses, quality and warehouse monitoring.

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BOOK REVIEWS

A Field Guide to Whisky

By Hans Offringa

This 'Field Guide to Whisky', produced in handsome and beautifully bound hardback, contains hundreds of facts, figures and interesting pieces of trivia for the whisky connoisseur. Written by the world renowned whisky expert Hans Offringa, the book is ideal for those wishing to learn a little more about how the whisky in their glass is made.

Covering the major whisky producing areas around the world, from Scotland to the USA to India, the book explains to the casual reader the basics of whisky ingredients and production, the differences between malt, Scotch, bourbon and rye whiskies, and whether or not your favourite dram truly deserves it's reputation.

Consisting of 323 short entries, there are plenty of interesting nuggets of information to keep even those already having an extensive knowledge of whisky amused. The facts, figures and triva makes for a fun alternative to some of the more encyclopaedic compendiums of worldwide whisky, and will serve well as a guide to those new to whisky also. There are 230 colour photographs, often showing production processes and equipment within famous distilleries that are not seen on tours, or in print.

Useful information on whisky festivals, bars, hotels, whisky trails and tours is also given, along with notes on consumption trends around the world. This all makes for an informative and very well presented small format book, which would be idea as a gift.

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About the Author:

Hans Offringa holds many titles in the whisky world: Patron of the Whisky Festival Northern Netherlands, Honorary Scotsman, Honorary Member of the Caledonian Society of Charleston (SC), Kentucky Colonel and Keeper of the Quaich. He is also the contributing editor for Europe for Whisky Magazine and a lecturer at the International Whisky School in the Netherlands. Offringa and his wife, Becky Lovett Offringa, are known as The Whisky Couple, and have been judges at the Dutch Whisky Awards since its inception.

