Welding stainless steel to meet hygienic requirements

Inadequate welding can compromise product safety in an otherwise hygienically designed food-processing plant. This paper summarizes guidelines prepared by the Design Principles subgroup of the European Hygienic Equipment Design Group (EHEDG) to increase awareness of the importance of and techniques required to ensure the production of hygienically acceptable welds. This is the tenth in a series of articles featuring the EHEDG to be published in *Trends in Food Science & Technology*. The EHEDG is an independent consortium formed to develop guidelines and test methods for the safe and hygienic processing of food. The group includes representatives from research institutes, the food industry, equipment manufacturers and government organizations in Europe.*

This paper, summarizing a document prepared by the Design Principles subgroup of the European Hygienic Equipment Design Group (EHEDG), aims to increase the general level of awareness of the techniques required to produce hygienically acceptable welds in thin-walled stainless steel used for food applications. Although primarily aimed at project and process engineers, it should be of interest to anyone involved in plant installation and maintenance, discussions with contracting companies, or factory hygiene. The basic elements of hygienic plant design and how they apply to welded joints are considered first, then common weld faults are discussed in relation to the hygiene risks they create and appropriate guidelines are summarized to describe briefly what constitutes a weld of hygienic quality.

The need for hygienic welds

A wide variety of vessels and pipework is used for the hygienic manufacture of food products. Most of this equipment is fabricated from austenitic stainless steel (e.g. type AISI-316 or its equivalents)[1]. Welding is the usual method of connecting the various component parts of a plant, and hence it is important to ensure that weldments reflect the hygienic qualities of the parent plate or pipework as closely as possible.

The design philosophy of a hygienic plant follows three central themes: product must flow freely through the plant and not stagnate; the plant must be cleanable, and must allow the destruction of microorganisms (see Definitions); and the contents of the plant should be protected from the external environment[2]. As a result, welds must also be subject to the same requirements. Poor welds can contribute to a number of hygiene problems, such as the retention of product in crevices, other dead areas or rough surfaces, all of which may be difficult or impossible to clean in the usual CIP (cleaning-in-place) cycle. Should such trapped product become contaminated, these regions could serve to inoculate otherwise sound product with microorganisms. Inadequate welding can therefore compromise product quality in an otherwise hygienically designed plant.

The primary purpose of a weld is to provide a joint of sufficient mechanical strength to function according to the design. Consequently, a weld must meet all mechanical strength requirements, notably where legislation demands certain standards (e.g. pressure vessel codes). Hygienic requirements, which can often be more demanding, operate in addition to mechanical considerations. Susceptibility to localized corrosion must be avoided, and the metallurgical properties of the weld must be as close as possible to the parent material. Furthermore, the introduction of new techniques, such as 'line pigging', demand a similar standard of welding.

Welding problems that affect hygienic security

Several types of common surface-breaking defects arising in weldments can act as a source of microbiological problems through inadequate cleaning and product retention:

- Misalignment can be due to several causes, from incorrect fitting up prior to welding to a mismatch in diameters or thickness. This introduces a step in the wall or bore, which can hold up product.
- Cracks penetrating the product contact surface can lodge material. The most common type is 'centre line cracking', a crack running along the weld metal itself, caused generally by having too wide a gap during the joint preparation.

Definitions*

Cleaning: The removal of soil (any undesired matter, including product residues, whether or not containing microorganisms).

Crevice: A surface defect that may adversely affect **cleanability** and that may harbour soil and microorganisms.

Destruction of microorganisms: Irreversible physical or chemical damage to microorganisms to prevent them from surviving and multiplying. **Thermal destruction** employs heat, possibly in combination with water or steam; **chemical destruction** employs biocidal chemical(s).

*These definitions have been drawn up by the EHEDG in an attempt to prevent confusion regarding terminology relevant to hygienic processing. For a complete list of definitions, please see Ref. 2.

* Readers requiring further information on the EHEDG are referred to *Trends in Food Science & Technology* (1992) Vol. 3(11), p. 277.

• Surface porosity, or excessive inclusions that may become detached thereby creating surface porosity, can trap product and be difficult to clean.

• Incorrect penetration of the weld can be caused by poor welding technique (e.g. poor control of the welding current) or incorrect parameters. Ideally, the weld metal should exactly fill the joint and remain flush with the surface. Underpenetration leaves a crevice at the joint (Fig. 1a), which is a hygienic problem both in vessels and pipework; excessive overpenetration can also hold up product in pipework, although the excess can be removed in vessels by grinding.

• Lack of full fusion of the weld metal in the joint to the parent metal results in crevice formation at the interface between weld and plate [associated mainly with MIG (metal inert gas) welding].

• Inadequate inert gas shielding (generally nitrogen or argon based) of the reverse surface, when welds are completed from one side only (e.g. pipework welds), results in a roughened weld and heat-affected zone (Fig. 1b); this promotes the adhesion of soiling and is difficult to clean.

Welding processes appropriate for hygienic fabrications

Many welding processes are in common use, but only a few can deliver welds of hygienic quality free from the types of defects outlined above. The most appropriate welding process is the gas tungsten arc welding (GTAW) process, commonly referred to as TIG (tungsten inert gas) welding (Figs 1c, 2). In this process, an arc is struck between a tungsten electrode shrouded with an inert gas and the workpiece. There is often an external feed of filler wire to the joint, although thin sections (<3 mm) can be joined without filler wire ('autogenous' welds). The filler wire is usually of the same composition as the parent plate, and special consideration is required if mixed metals are involved. In some cases it may be desirable to use a higher-alloy filler wire.

The TIG process can be used for pipework and for thin sheet up to ~4 mm thick; a manual metal arc process, followed by post-weld grinding, would more likely be used for thick sections. For many hygienic applications, thin-walled vessels and pipes are commonly used.

Automatic (non-manual) versions of TIG welding are now becoming popular and are available for both vessels and pipework. The major advantages of automation are that once the parameters have been established for the geometry and thickness of the joint, high-quality reproducible welds are formed, and that to some extent the operation demands a lower level of skill than hand welding. It is preferable to use the automatic process wherever possible.

A surface roughness (R_a) of 3–4 μm can be achieved on high-quality TIG welds, though R_a values of 7–8 μm are more likely on 'industry standard' welds. This is a little higher than ideal, but is acceptable as the weld area is relatively small overall; however, allowance may be necessary for the additional cleaning times required.

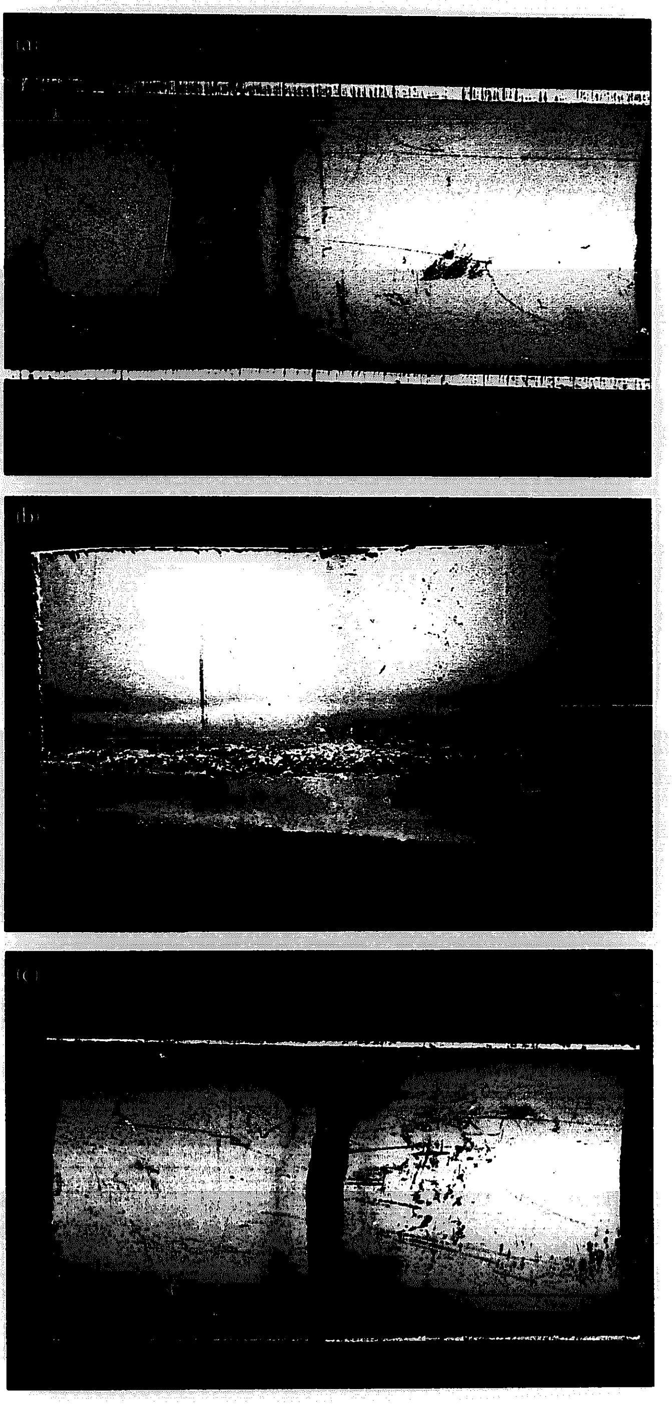

Fig. 1
(a) Lack of penetration leaves a crevice that can trap product at the inner surface of the weld joint. (b) Roughened weld and heat-affected surface resulting from inadequate inert gas shielding; such a surface promotes the adhesion of soiling and is difficult to clean. (c) Example of a high-quality manual TIG weld.

The main drawback with TIG welding is the low speed at which the weld runs are accomplished, particularly for thicker-walled vessels. A technique with a faster deposition rate, such as MIG or MMA (manual metal arc) can be used on top of a TIG root run adjacent to the product.

A number of companies specialize in the fabrication of stainless steel plants for the food and pharmaceutical

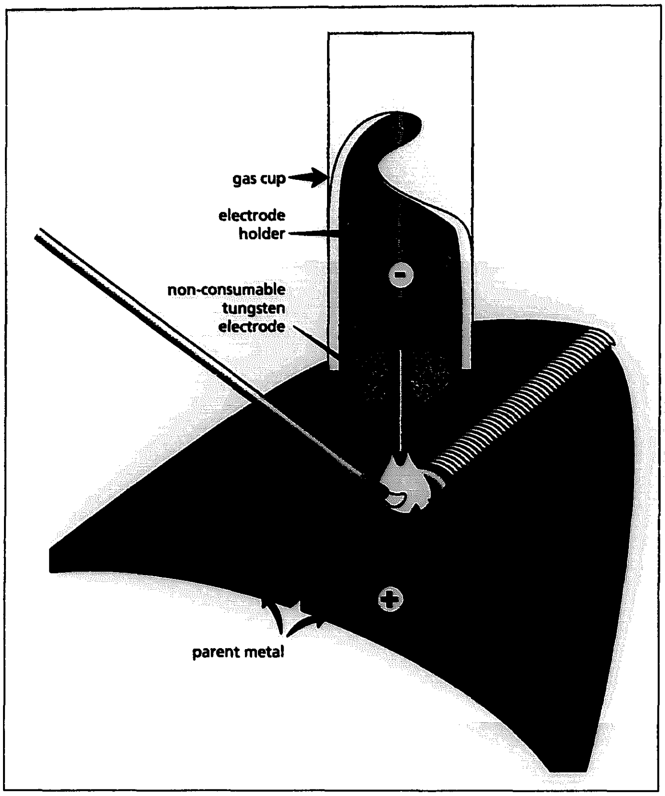

Fig. 2
Gas tungsten arc welding (GTAW), commonly referred to as TIG (tungsten inert gas) welding. Gas shielding is necessary around the tungsten electrode as well as behind the weld, internal to the pipe, to prevent the formation of a roughened surface on the reverse side of the weld (see Fig. 1b).

industries, and the facilities and experience available in these companies is generally superior to those of standard fabricators for the chemical process industry. These companies are familiar with the need to protect surfaces during fabrication. In particular, the segregation of stainless steel fabrications from ferrous areas is important, since the use of tools and forming equipment impregnated with ferrous debris can lead to corrosion problems in the finished plant.

Hygienic fabrication of vessels

In order to achieve good cleanability of a vessel surface, it should be smooth; the target value is usually 0.8 µm R_a (Ref. 3). This is achieved in practice by using cold rolled sheet (e.g. type 2B surface finish)[4], typically of ~0.3 µm R_a, which is available for vessels up to ~4 mm wall thickness. The sheet should be protected with a vinyl layer. This can be left in place during forming and removed on completion of fabrication; a narrow band (~50 mm) is usually removed from the proposed weld line to facilitate joining and avoid contamination.

The weld area does not generally require any special preparation for thin sheet, but must be free from grease and dirt. Usually, two runs are applied from opposite sides. The first run will become oxidized on the reverse side, and this must be ground back to sound metal before applying the second run. This must then be ground back flush with the parent plate and polished to restore the surface finish; a final polish at 150 grit size is sufficient to give the required surface roughness.

Box 1. Checklist for hygienic welds in Type AISI-316L austenitic stainless steel pipework

- The pipework and fittings should have an internal surface roughness of 0.8 µm R_a maximum.
- TIG (tungsten inert gas) welding, also referred to as GTAW (gas tungsten arc welding), must be used as the welding process. Other processes will not give adequate hygienic welds.
- Orbital welding machines should be used wherever possible for reproducible high-quality welds. However, manual TIG will be necessary in some cases.
- Welders of proven competence, for example coded for pressure vessel work (BS 5500, ASME VIII, or to appropriate National Pipework Standards) should preferably be used.
- The pipe system should be designed such that butt welds are the only construction requiring welding. Pre-assembly of sections in controlled conditions prior to final installation is recommended.
- The weld must exactly fill the gap between pipe ends/fittings: there should be no underpenetration or excessive overpenetration, and no surface weld defects (e.g. inclusions, porosity, lack of fusion, cracking).
- The internal surface must be gas shielded during welding, ideally with an argon purge gas, although nitrogen is acceptable.
- Pipe ends must be clean in the fusion zone, and should be cleaned with a stainless steel brush and solvent to remove dirt and grease.
- Pipe ends must be cut square with the pipe axis, using mechanical means (not by hand), and be free from burrs and distortion. If weld preparations are required (e.g. for wall thicknesses greater than ~3 mm), they should not be cut by hand.
- Prefabricated fittings (T's, elbows, etc.) are required, and these must be consistent with the standard of pipework.
- The pipe diameters should be the same; otherwise the smaller must be expanded with a specialized tool, to avoid creating a step and a poor weld.
- Misalignment must be limited to <20% of the wall thickness
- Trial runs / test pieces are required to establish the optimum conditions for the actual pipe wall thickness used.
- Welds may be removed from the installation for inspection if so agreed in advance.

For thicker-walled vessels, the stainless steel is usually available as hot rolled plate with an R_a value of ~5 µm, unacceptable for hygienic processing in the as-received condition. Thus, after grinding the internal weld bead flush with the surface, the whole vessel must be polished to the required finish.

Hygienic fabrication of pipework

The requirements for hygienic welds in stainless steel pipework are summarized in Box 1.

Orbital welding, an automated version of manual GTAW (TIG), is recommended for the straightforward butt welding (Fig. 3a) of pipework. A good manual welder can produce welds to the same quality as orbital welding. However, although manual welders may start the day producing excellent-quality welds, their concentration may drift as they grow progressively tired and distracted, resulting in the production of substandard welds later during the day. Furthermore, welds are not always in easily accessible or straightforward positions

With orbital welding this may be overcome with the selection of a specific type of weld head, but with a manual welder quality may suffer with the ability of welder to work well at full stretch, in cramped conditions, often needing to use mirrors to see the complete weld. An orbital welding machine, once set up correctly, will repeatedly produce welds of the defined quality with no variation. However, orbital welding is extremely sensitive to the setup procedure. Being automatic it cannot compensate for any irregularities, for example misalignment or variations in pipe diameter.

There should be no time penalty when using orbital welding equipment. In fact, when a machine operator is fully competent, productivity in comparison with manual welding should rise.

Top-of-the-range models can be connected to external personal computers, enabling exact measurement of variables (e.g. weld current, pulse setting, speed of travel of weld head and filler wire feed) against set parameters for each weld, and the ability to abort welds in progress if the variables are not maintained within the set limits.

Applicability of orbital welding

Orbital welding should be used wherever possible in an installation. Typically it is considered that 80–90% of welds on an installation can be completed with an orbital welder. From isometric drawings of the installation, a degree of preplanning will help maximize the number of welds to be orbitally welded. Those welds difficult to access should, wherever possible, be completed in the workshop prior to installation in the plant.

Instances where orbital welding may not be possible are areas of restricted access (the physical size of the weld head may prevent its use in cramped areas) and cases where there is insufficient pipe length to clamp the pipes and weld head together (e.g. pipe bends and T pieces). Prefabricated, extruded Ts and elbows are therefore recommended; typical minimum straight lengths required range from 3 mm to 5 mm depending on the weld head type.

Pipe diameters

The outer diameter of a pipe from a set supplier of a certain standard can vary by ±10%. In addition, tube manufacturers may produce a wide range of standard sizes that can be quite similar (e.g. metric and imperial sizes). Another complication is the availability of pipework made to various different standards, for example ISO or ANSI. Where possible, it is important to avoid mixing different pipe standards; otherwise misalignments can occur.

If the diameters of two pipes to be joined are not the same, then the smaller pipe should be expanded to match the larger. Specialized hydraulic expanding tools are available for this purpose, ensuring the pipe remains cylindrical.

Pipe cutting and surface preparation

A mechanical mill or saw should be used to ensure that the cut face is exactly at right angles to the

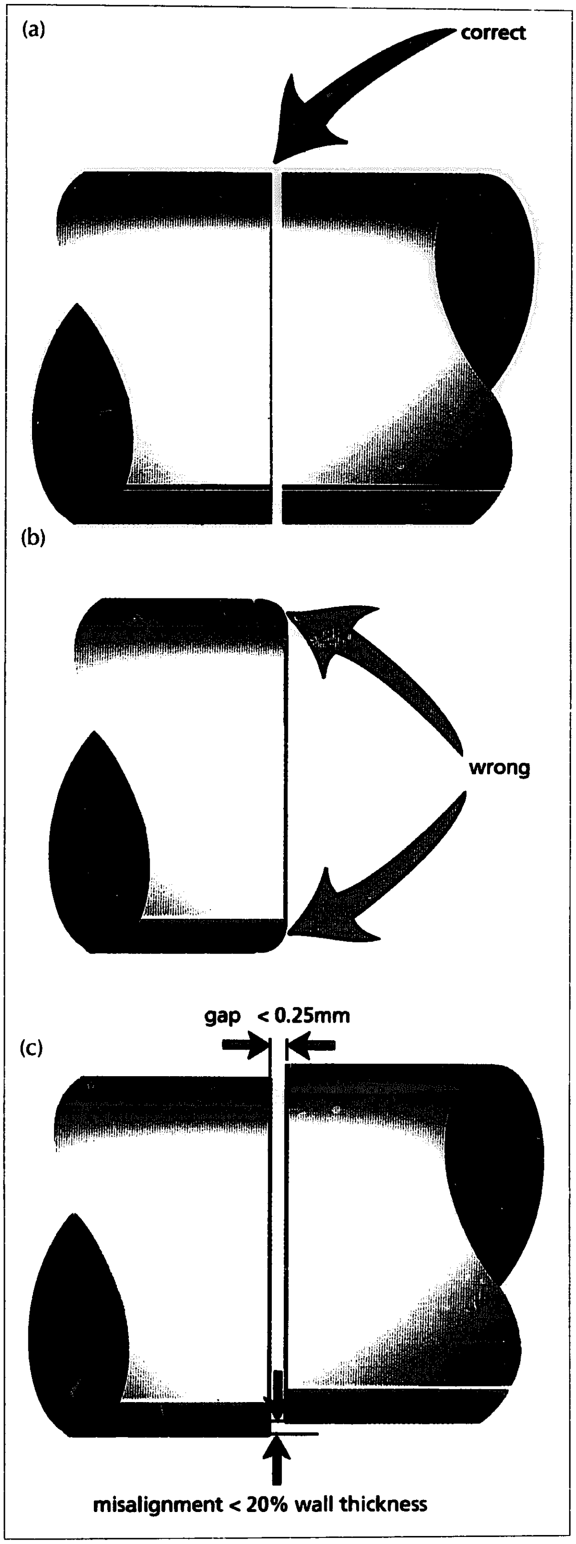

Fig. 3
Preparation is the key to obtaining a good-quality weld (a). Pipe ends should be cut at right angles and care should be taken to avoid removing the corner edges (b). Pipes to be joined should be flush and should be of the same wall thickness and diameter to avoid misalignment (c).

longitudinal axis of the pipe. Any burrs must be removed with either a file or emery paper. Care must be taken to avoid removing the corner edges of the pipe (Fig. 3b), as this can cause problems with fusion of the root of the weld.

The pipe surface 25 mm either side of the weld should be roughened up with a stainless steel wire brush or emery paper, then both the pipe ends and the roughened surface area should be degreased with a solvent. Failure to do so leads to porosity in the weld, as any organic substances remaining on the metal surface are vaporized during the welding process and form bubbles in the weld metal.

Pipe alignment

Alignment and clamping tools are available to ensure accurate alignment. However, this accuracy should be checked periodically with the wear of the instrument. Misalignment must be limited to <20% of the maximum wall thickness. There should ideally be no gap between pipe faces, but <0.25 mm is acceptable (Fig. 3c).

Post-weld treatments

Product contact weld surfaces fall into two categories: those which are accessible (e.g. vessels), and those which, once completed, remain inaccessible during their service life. Accessible welds are often ground and polished as described earlier; inaccessible welds should be completed such that further treatment is not required. The next stage in either case is to wash the internal surfaces, once any protective film has been removed.

Washing may consist of several stages. A degreasing treatment may be applied to remove grease and oily residues. In general, all surfaces should be cleaned by washing with an alkaline detergent solution, followed by rinsing with water of good microbiological quality, usually cholorinated water to 2 ppm available chlorine maximum. After draining, the access points should be covered and sealed. In some circumstances there is an additional requirement to passivate the weld area on the product contact side. This is normally achieved by the use of, for example, nitric acid solutions, increasing the corrosion resistance of the weld area.

The external welds may also need treating. Where excellent cleanability of the external surface is demanded, weld beads should be ground smooth and polished. It may be undesirable to grind autogenous welds since this can lead to thinning in the weld area and consequently to mechanical or safety issues. However, where external cleaning is less important it may simply be possible to remove the 'heat colours' from the weld area with a proprietary 'pickling paste', followed by cleaning; the treatment used will depend upon the external cleaning requirements.

Quality assurance and inspection for hygienic welds

A hygienic weld should be produced using a quality assurance approach, since in many cases final inspection can be difficult or impossible (e.g. in pipes).

The general approach is first to prepare a specification of the requirements, including the defect acceptance criteria and surface finish. Essentially there should be no surface-breaking defects as outlined in the section on problems in welding; these requirements may be in addition to more stringent requirements such as relevant pressure vessel codes. The method of inspection and repair procedures also needs to be agreed at the outset.

Prospective fabricators can be audited for their fitness to manufacture by considering the general approach and layout of the workshop, and the qualifications of the welders. Representative samples of workmanship should be requested, examined, and if acceptable used as a reference for the standard required in the plant.

Few techniques are suitable for the inspection of stainless steel equipment. Great reliance is placed on visual inspection of weld seams in vessels, aided by dye penetrant tests for highlighting surface defects. The surface finish of polished weld seams can be measured using portable equipment such as the Surtronic 10 surface roughness indicator (Rank Taylor Hobson, Leicester, UK). Pipework is more restricted, with visual inspection by fibre optic devices inserted down the pipe the only realistic option. Of course, sample welds can be cut out for destructive assessment; if this course is followed, it must be by prior agreement in the specification, and the action level should have been agreed. For example, the right to remove 2% of welds may be requested, and the welds remade if the work is found to be substandard by comparison with the agreed test samples.

For critical applications, a more rigorous approach is required. Each weld must be identified with a unique reference, and for convenience grouped into segments. This can be achieved simply in pipework systems by grouping together all welds using the same gas purge. If there are failures in the group, then 100% of the welds for that segment should be examined. External inspections of all welds should be carried out. A documented record indicating the identity of the welder, inspection details and outcome, together with weld variables may be required.

Acknowledgement

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This paper summarizes guidelines recommended by the European Hygienic Equipment Design Group (EHEDG) subgroup on Design Principles, and has been approved by the EHEDG. The full report, by C.A. Eastwood, D.L. Woodall, D.A. Timperley, G.J. Curiel, P. Peschel and G. Hauser, is available from: D.A. Timperley, Campden Food and Drink Research Association (CFDRA), Chipping Campden, UK GL55 6LD (tel. +44-386-840319; fax: +44-386-841306).

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