

# Intelligent Systems for the Brewery Based on Real-Time Measurement of Biological Parameters

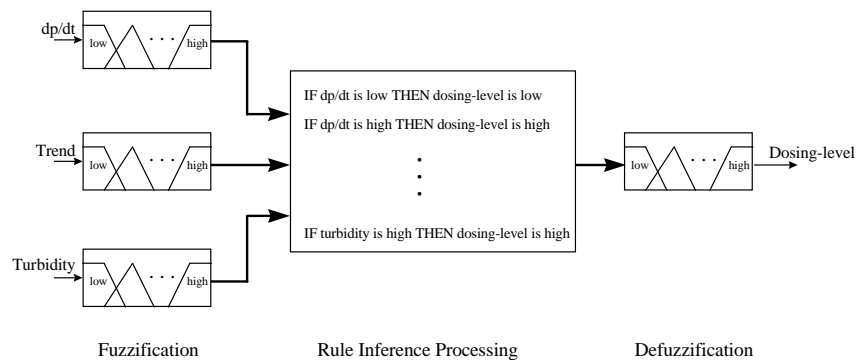
Michael Lees<sup>A</sup>, Peter Rogers<sup>A</sup>, Duncan Campbell<sup>B</sup>, Michael Pecar<sup>A</sup>, David Sudarmana<sup>A</sup>

<sup>A</sup>BrewTech, Carlton & United Breweries, 1 Bouverie Street Carlton 3053, Victoria, Australia.

<sup>B</sup>La Trobe University, Bundoora 3083, Victoria, Australia.

Beer is judged by its physical and sensory characteristics. Traditionally these properties were managed by the *Master Brewer* who controlled the process based on prior art, knowledge and experience. In modern breweries, the position of Master Brewer has largely been devolved into component functions, some of which capture the old art of the Master Brewer, but most of which are associated with the control of process sequence. Physical parameters can be measured with accuracy. Most chemical and biochemical characteristics are not readily measurable on-line and are usually analysed in the laboratory. On-line assessment of biological parameters should provide a coherent data base for decision making and process management using artificial intelligence based systems. The challenge is to develop a suite of sensors that can measure compounds that define the critical steps in the process as well as those compounds that predict beer stability and sensory quality.

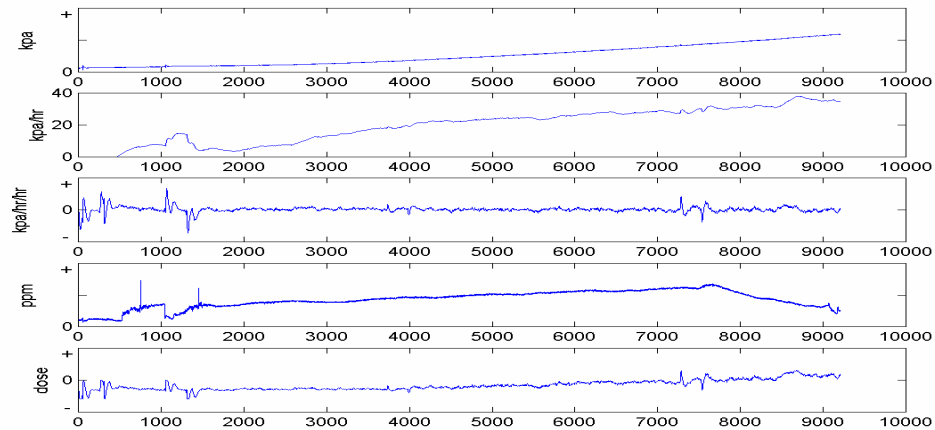
CUB has investigated the application of intelligent systems for palletisation optimisation, fermentation, predicting mash stand-time and optimisation of filtration (Campbell *et al* 1998). These projects have shown that intelligent systems can significantly improve efficiency throughout the brewery. An intelligent system for controlling beer filtration has been developed. Diatomaceous earth (DE) filtration removes yeast cells, chill haze and particles from storage beer. DE is added to the beer prior to filtration. Feed beer generally varies in solids content and composition; usually DE is overdosed to compensate for any unforeseen large changes in the incoming feed beer quality.



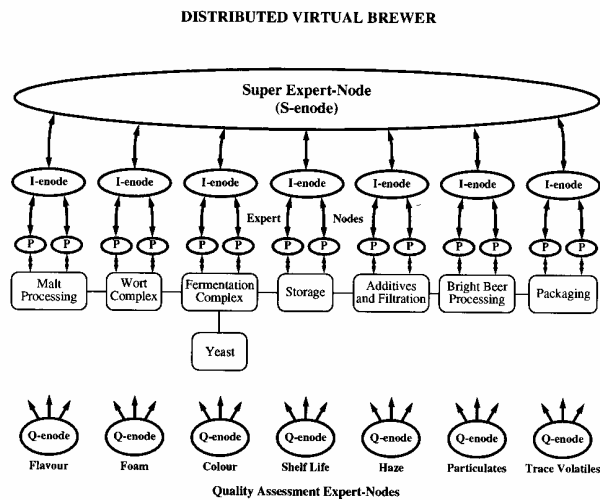
**Figure 1.** Architecture of fuzzy controller for DE filtration: The relation between the input and output variables are shown relative to an example rule-base. The expert knowledge has been implemented in the form of 'IF THEN' rules. As the observable and controllable parameters of the filtration system are 'crisp' (non-fuzzy) values, the fuzzy system must perform domain transformations in order to interact with these values. The first of these transformations is commonly known as fuzzification, and is the process through which the crisp input parameters are converted into their fuzzy equivalents. The second domain transformation (defuzzification) occurs at the output of the fuzzy system, where the fuzzy output of the rule inference processor must be converted into its equivalent crisp value, (as a crisp/numerical value is required to control the dosing pump).

A three-input, single-output fuzzy logic control system has been devised (Figure 1) and has since undergone plant trials (Figure 2). This system optimises DE consumption, leading to

consistent beer quality and increased filter-run duration. (Campbell *et al* 1998; Pecar *et al* 1999).



**Figure 2.** Example of minimising bodyfeed consumption (Pecar *et al* 1999). The incoming turbidity (ppm) has remained reasonably low throughout this portion of the filter run and hence (in this case) has had very little influence on the control of the bodyfeed dosing rate. Under conditions of low turbidity, the controller will modulate the bodyfeed dosing rate, so as to maintain a rise in differential pressure of around 30kpa/hr.



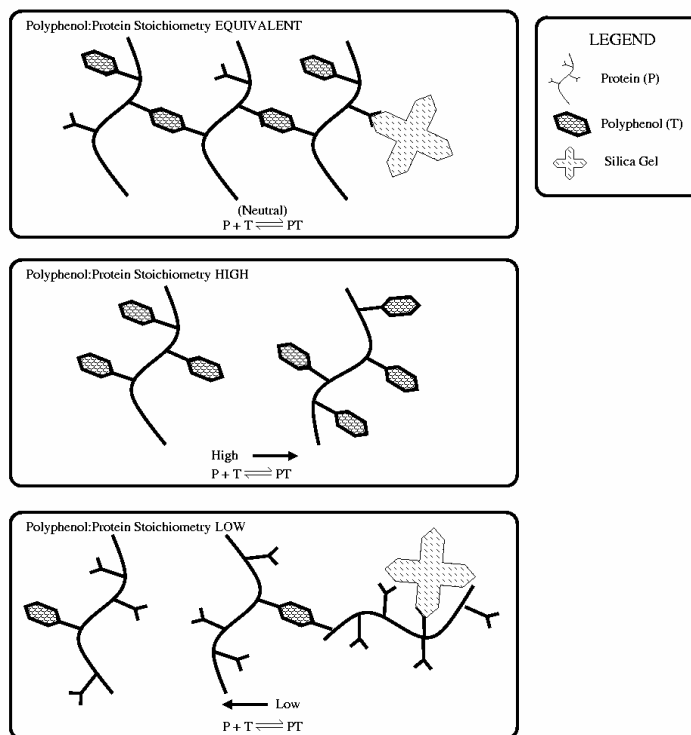
**Figure 3.** Structure of the intelligent brewery. A hierarchical structure has been used for the intelligent system, with modular sub-systems being allocated to specific component functions. Four types of expert-nodes are shown: P-nodes deal directly with operation of individual pieces of process equipment, I-nodes deal with an entire area of the process, Q-nodes deal with particular quality issues that are related to the final beer product (and rely on sensory input from all stages of the brewing process), the S-enode is the overarching intelligent system that co-ordinates all other expert nodes.

Similarly an intelligent learning system has been developed to estimate the stand-time of the mashing process; that is, the time required to extract and digest the malt carbohydrate (and adjuncts) to the appropriate ratio of fermentable and non-fermentable sugars. This expert system will replace the present practice whereby an operator estimates the stand-time for each brew. This system takes the guess-work out of the process and offers a pathway towards automation in the brewhouse. For most breweries seasonal and varietal changes in malt

characteristics mean that the mashing-in process requires constant revision for each brew. In a broader sense, these projects are part of an overarching concept referred to as the intelligent brewery (Figure 3) in which a family of interacting intelligent systems provides data acquisition, assessment, interpretation and decision making.

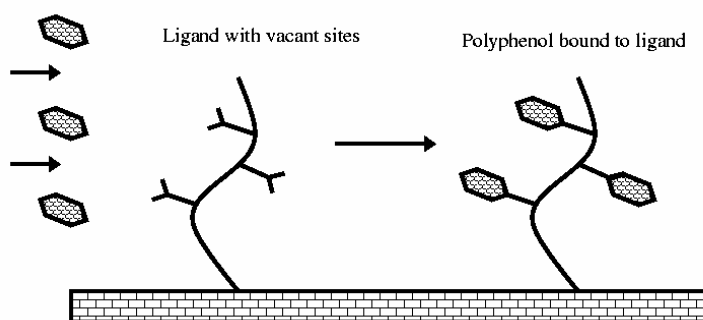
The two examples described above are part of the *process expert node* (P-enode) array as they control tasks within each process module. Larger regions of the plant, such as the wort complex, are under the control of *intermediate expert nodes* (I-enodes). The *quality expert nodes* (Q-enodes) evaluate the product at multiple stages during the process to determine/predict what the final beer quality will be in terms of sensory and physical properties such as flavour, foam, mouth-feel, volatiles and haze.

The development of Q-enodes (Figure 3), relies on real-time measurement of biological parameters. Foam stability depends on protein, polysaccharides and alpha acids. Reversible and permanent haze is produced by reactions between haze active proteins and polyphenols. Beer may be stabilised by removing polyphenols and acidic proteins with polyvinyl-pyrrolidone and silica gel respectively. Measurement of specific protein composition and polyphenol levels would allow more efficient use of stabilisers and control over the retention of foam-promoting proteins during processing.



**Figure 4.** Variable polyphenol:protein stoichiometry in beer can effect the size of haze particles and limit the efficiency of silica gel adsorption and removal of haze active proteins from beer (Siebert *et al* 1999). When the polyphenol:protein stoichiometry is equivalent the polyphenol forms crosslinks that couple haze-sensitive protein together to form extended flocs. When the polyphenol:protein ratio is very high all the binding sites are occupied and the particles that form are smaller. When polyphenol is limited, the particles become larger again. Note that the silica gel binds to the same protein sites as polyphenol, and hence high polyphenol levels diminish the ability of silica to remove unstable protein from the beer stream (eg. Middle diagram of Figure 4).

Many of the emerging biosensor technologies are based on molecular recognition, the most common example of which is antigen-antibody binding. Combinatorial chemistry technologies provide a means of tailoring molecular shape to produce ligands with specificity against a myriad of compounds and with appropriate stability for the brewing process. There are a number of at-line technologies that provide rapid (order of minutes) analyses for determining specific proteins, vitamins and polyphenols. The Biacore company has developed a flow through sensor cell that uses plasmon resonance technology to measure proteins and potentially polyphenols (Rogers *et al* 1999).



**Figure 5.** Biacore technology is based on capture of analytes by affinity ligands. Polyphenol binds to the immobilised ligand and saturates the binding site. The Biacore plasmon resonance sensor responds in resonance units which increase in proportion to the mass of polyphenol bound. Regeneration of polyphenol-free ligand is performed with an alkali solution.

These emerging technologies are capable of directly assessing biochemical parameters in wort and beer, although their stability and output during long term operation may be an issue. Nevertheless, we should anticipate their arrival and the fact that malt performance will be able to be judged from outcome measurements throughout the beer making process.

Automated systems and expert systems as applied to breweries have traditionally interacted with physical or chemical control points and parameters of the process (ie. pressure, temperature, flow rate, pH). A plant process control regime based on these types of parameters is inherently sub-optimal as these parameters are related to the process itself and are only indirectly linked to the wort, beer or the original malt. The integration of on-line biosensors into intelligent real-time assessment and control systems, will provide a much greater level of control over both the process (ie. optimisation of resource usage etc), as well as the beer itself (ie. sensory characteristics).

## References

- D. Campbell, M. Pecar, and M. Lees. (1998). "Intelligently Controlled Beer Filtration", *JCIS'98 Proceedings*, **1**, pp. 313-316
- M. Pecar, M. Lees, and D. Campbell. (1999). "An Alternative Control Strategy for D.E. Dosing Rates of Primary Beer Filtration", *CHEMECA'99 Proceedings*, (In-press)
- P. Rogers and E. Filonzi. (1999). "The Application of Surface Plasmon Resonance Biosensor Technology for Measurement of Specific Proteins in Beer and Wort", *Proc. American Society of Brewing Chemists*, abstract-P22.
- K. Siebert. (1999). "Protein-Polyphenol Haze in Beverages", *Food Technology*. 53(1), pp. 54-57.