Mixed-Culture Beer Fermentation: A Data-Driven Approach to Real-Time Multi-Variate System Modelling and Predictive Process Control

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The beer brewing sector has seen rapid and radical changes in recent years. During the previous decade alone, the number of independent breweries in the UK has more than doubled, spurred by the ever-increasing popularity of the craft beer movement. Craft beer is renowned for originality, novel beer styles, and unique flavour characteristics; a notable area of innovation within the craft movement has been the rediscovery and development of beers fermented using mixed-culture inocula. Mixed-culture fermentation is highly advantageous for breweries seeking distinctive flavours and beer characteristics. However, compared to pure monoculture fermentation, mixed-culture fermentation has significantly more biochemical complexity. Therefore, the production of consistent mixed-culture fermented beer, particularly at scale, presents a substantial brewing and engineering challenge. Consequently, there is a growing demand for cost-effective predictive process control and system modelling of mixed-culture beer fermentation processes, improving batch-to-batch product consistency and offering decision support to brewers. Therefore, this paper proposes an empirical, data-driven approach to multi-variate system modelling and real-time predictive process control for mixed-culture fermented beer. Training and testing data were generated using a sensor array monitoring critical fermentation parameters of pure monoculture and mixed-culture co-fermented beers brewed at pilot-scale. These data were used to train and test machine learning and artificial intelligence algorithms, producing an effective system for monitoring and estimating critical system parameters. The system effectively simulates and predicts fermentation behaviour for monoculture fermentations using ale and lager yeasts in addition to co-fermented ale and lager yeast mixed-culture fermentations in real-time. However, while the system proved effective for this application, there is significant scope for future work in this area. Specifically, future work is required to generate training datasets of real-world mixed-culture fermentations, particularly of yeast and lactic acid bacteria co-fermentations.