Optimization of energy and water consumption in milk cooling on dairy farms

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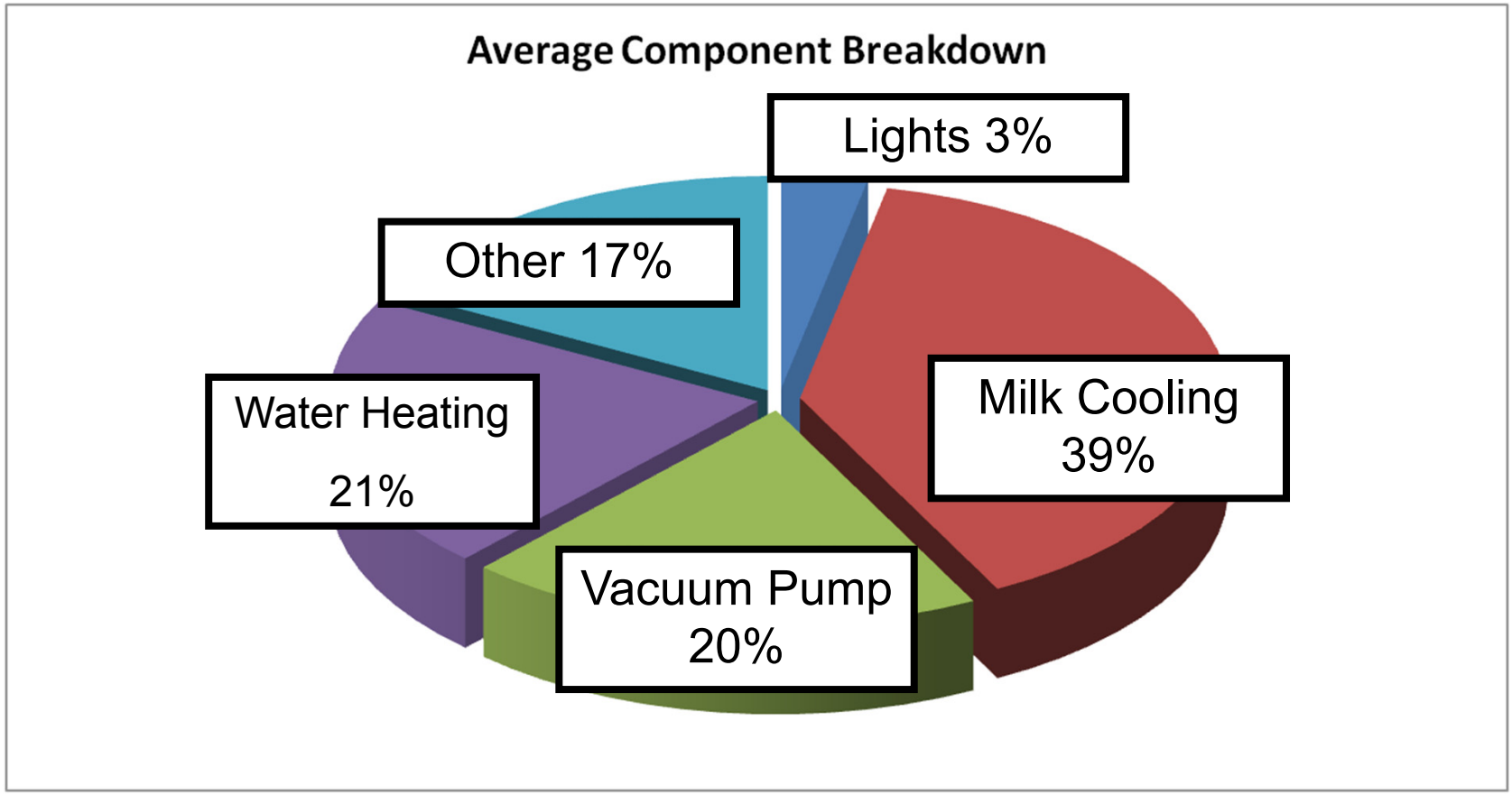
Background

- Key factors influencing the future of dairy production in Ireland:
  - Abolishment of European milking quotas in 2015.
  - 50% expansion in milk production due to government Food Harvest 2020 policy (DAFF, 2010).
    - Issues with milk quality relating to lack of cooling capacity.
- Continuous increase in resource costs:
  - 10% increase in electricity price since 2012 (CER, 2012).
  - Roll out of Irish water metering in 2014.

Dairy Farm Energy Audit



Average Component Breakdown of Energy Consumption on Irish Dairy Farms (Upton et al., 2013)

Milk Cooling

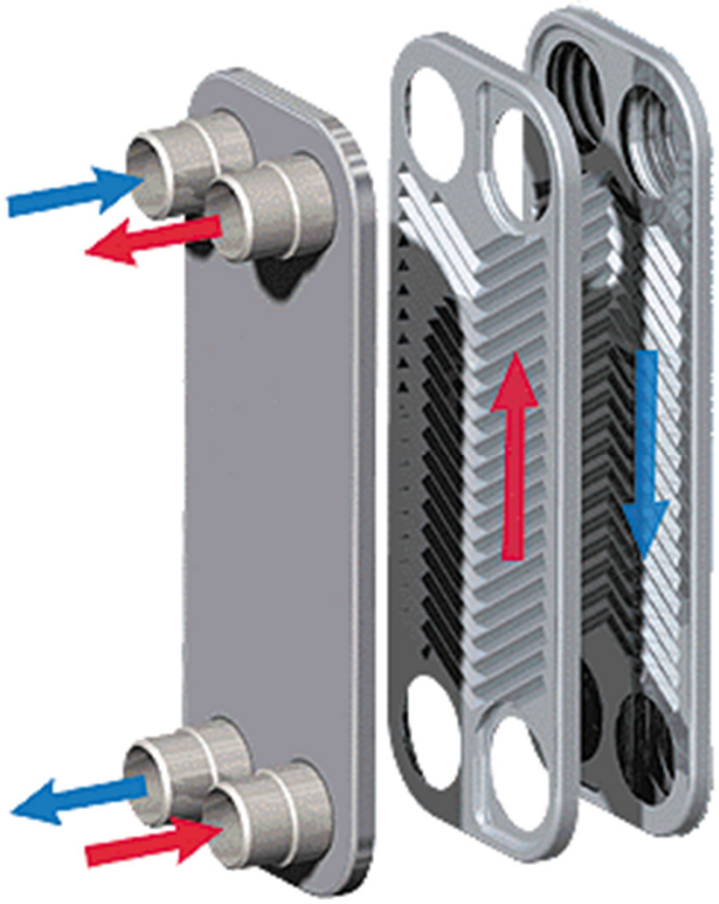
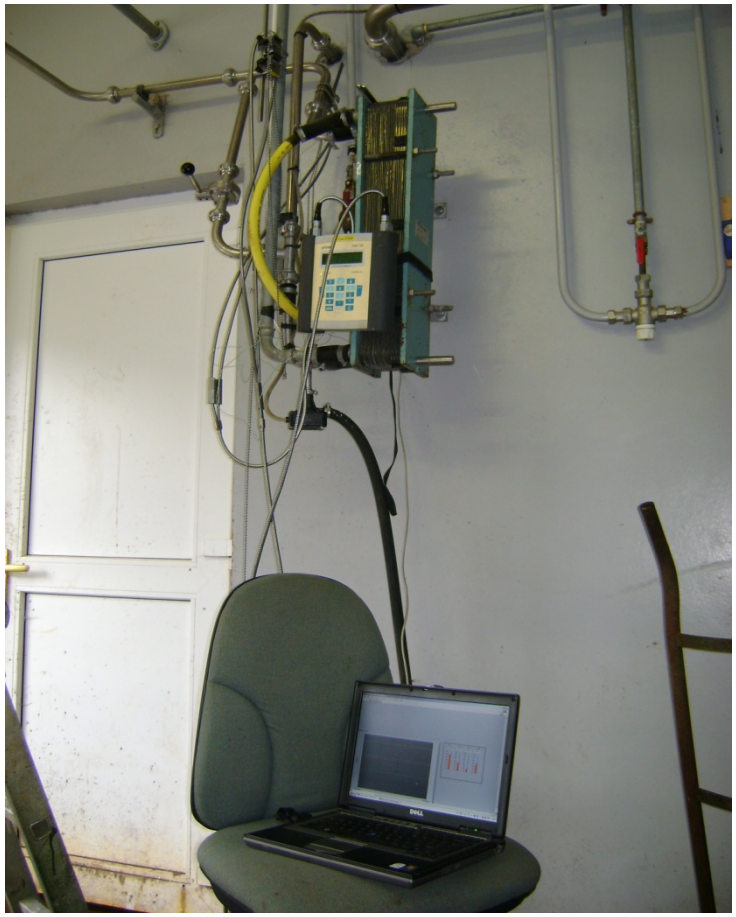


Plate Heat Exchanger (PHE)

PHE Audits



Flow rate and temperature logging

VSD frequency logging

Problem Statement

- Rapid milk cooling not being achieved using current start of the art.
  - Problems regarding quality produce and exports.
  - Issue must be addressed as dairy production expansion begins.

- Complete lack of resource control in the milk cooling process.
  - Wastage of water
  - Energy inefficiency
  - Great potential for optimization

Objectives

- To develop a rapid milk cooling control system.
  - Near-instant cooling below 4°C.
  - Load control.
  - Cold Thermal Energy Storage (CTES) required for rapid cooling

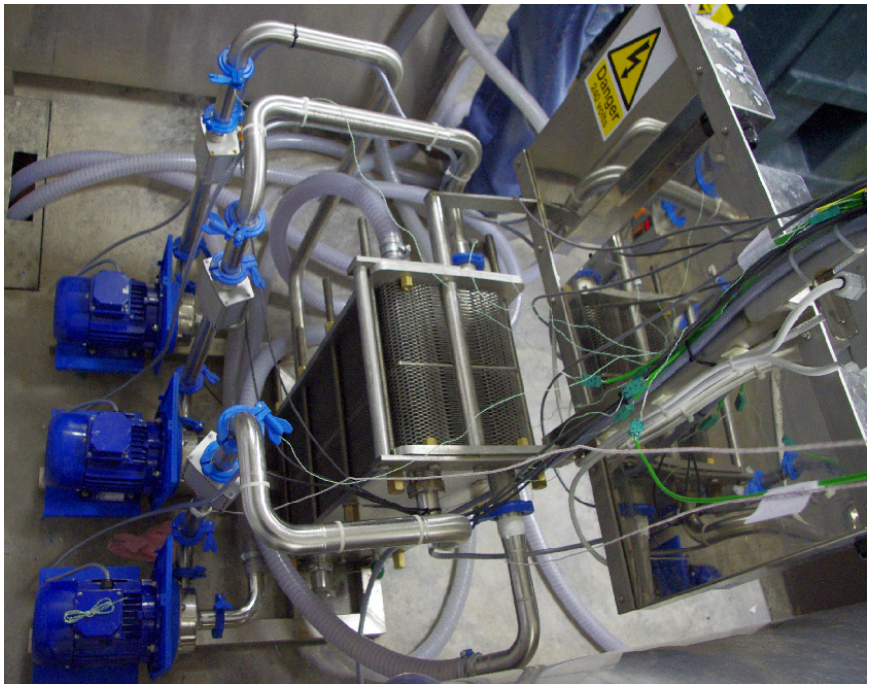
- To investigate the potential for electricity and water optimisation.
  - Milk cooling model.
  - Test the apparatus using varying water ratios.

Variable Flow Milk Cooling

- Cold Thermal Energy Storage (CTES) required for both rapid cooling and variable flow milk cooling load.
  - Ice Bank (IB) prototype (full scale) was designed and manufactured.

- To variable milk cooling a dual stage Plate Heat Exchanger (PHE) test rig was developed.
  - Variable speed dual stage PHE pumping system was designed and manufactured.

PHE & Milking Machine Apparatuses

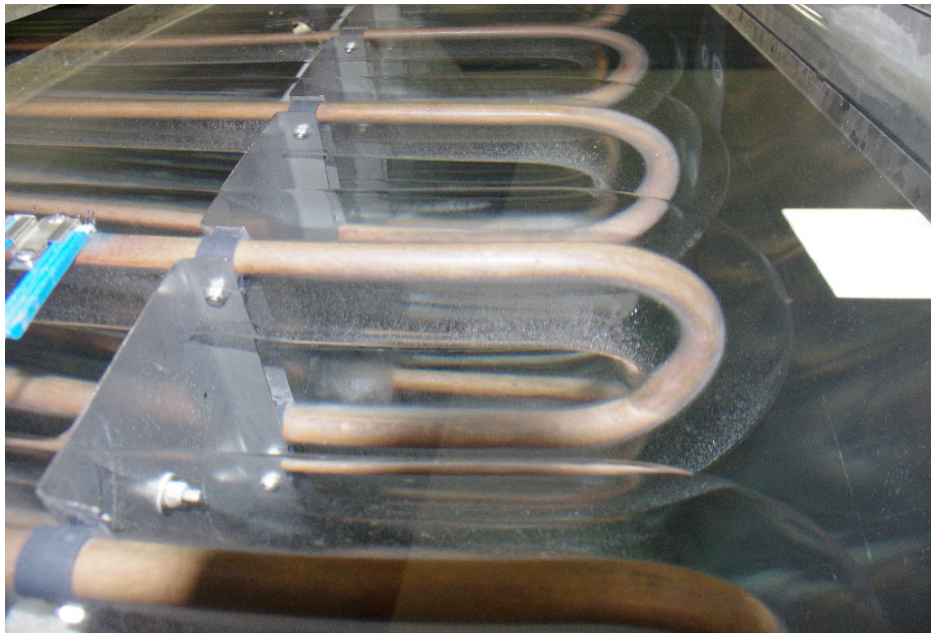


Dual stage PHE Test Rig

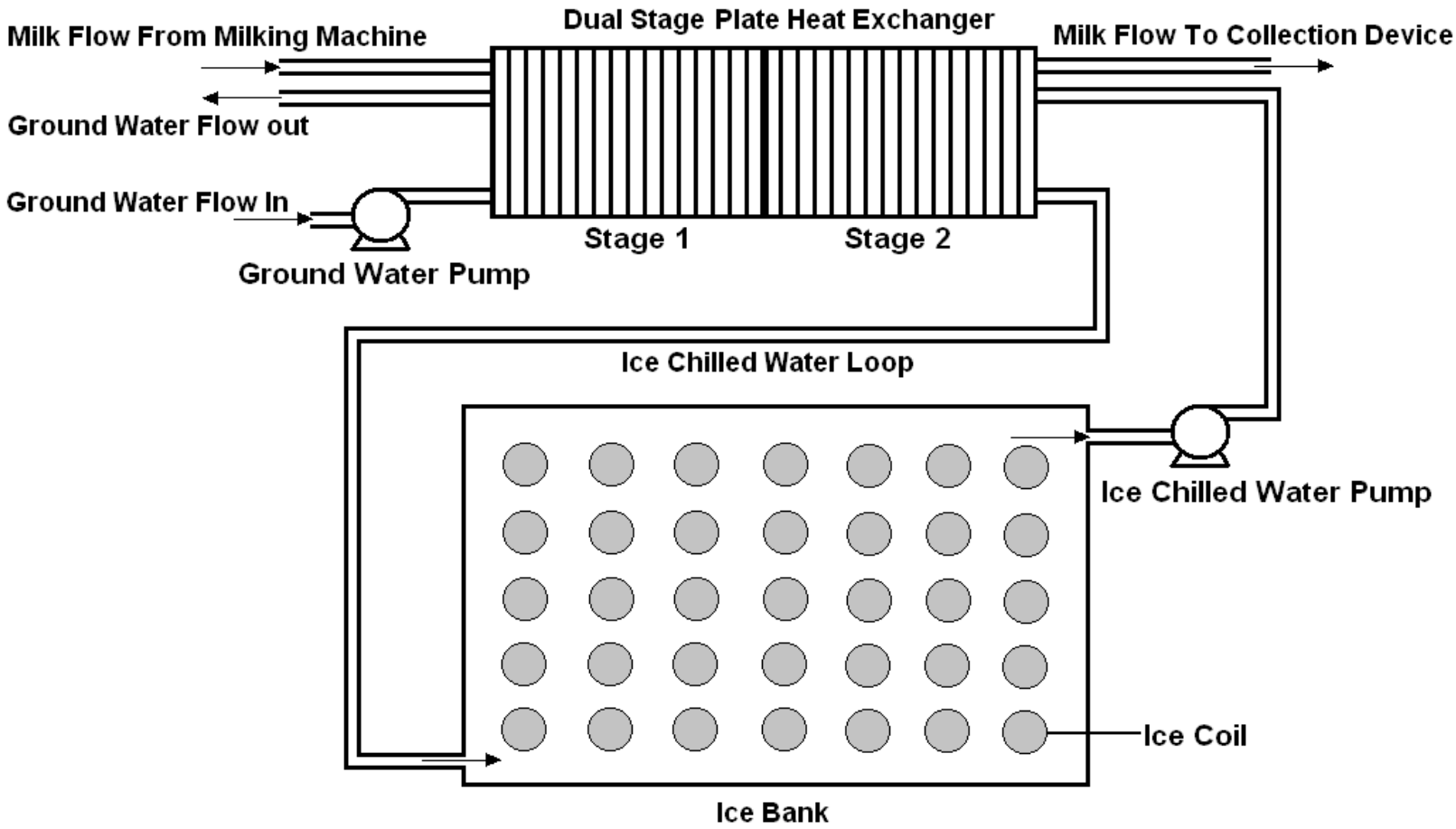
Variable Flow Milking Machine

CTES IB System

Ice Bank System

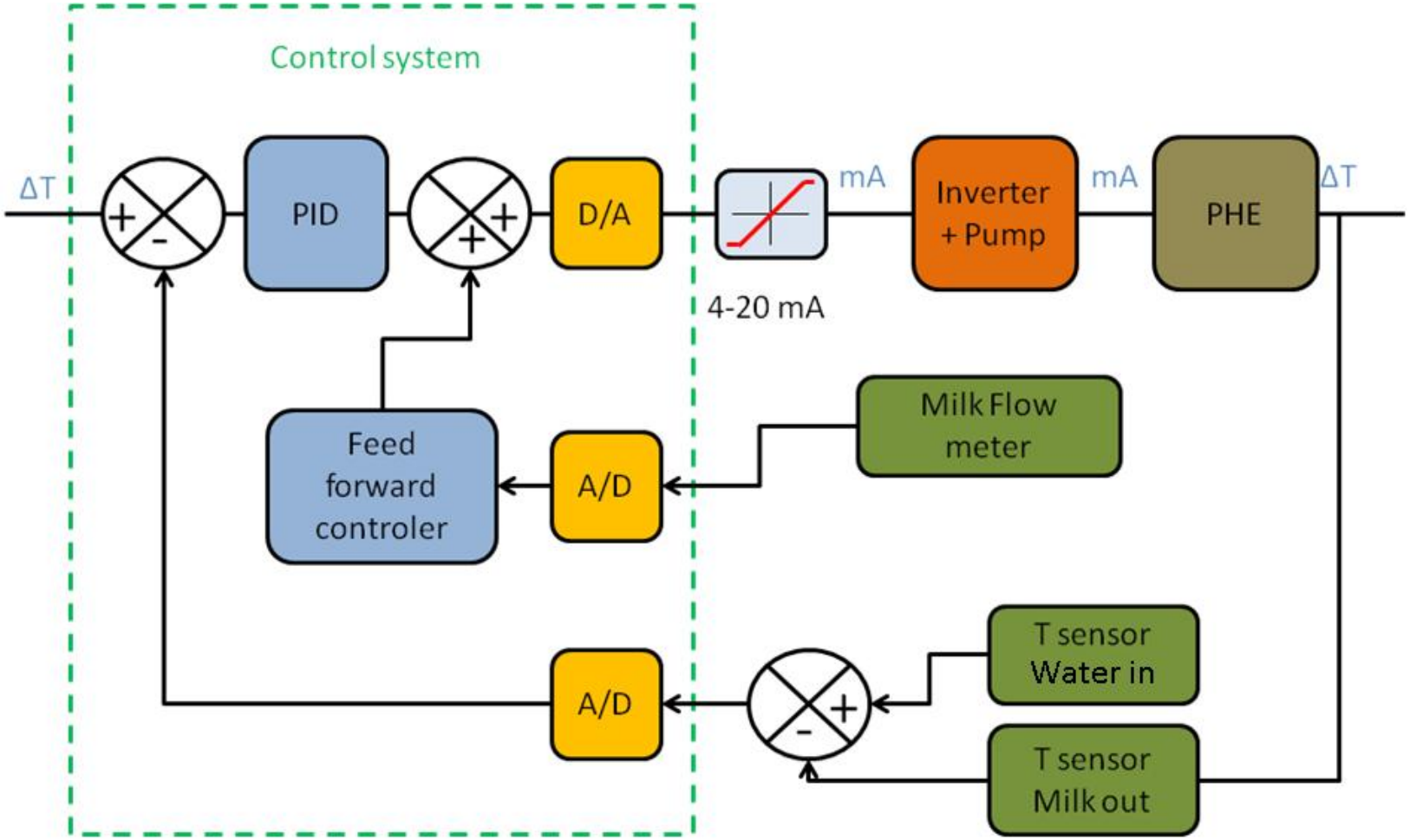


Ice Coil Evaporator



Schematic of the dual plate heat exchanger (PHE) used for instant milk cooling with ground water (GW) used for pre-cooling in the first stage and ice chilled water (ICW) used in the second stage (arrows indicate flow direction

Feed Forward Control Loop



Rapid Cooling Control System

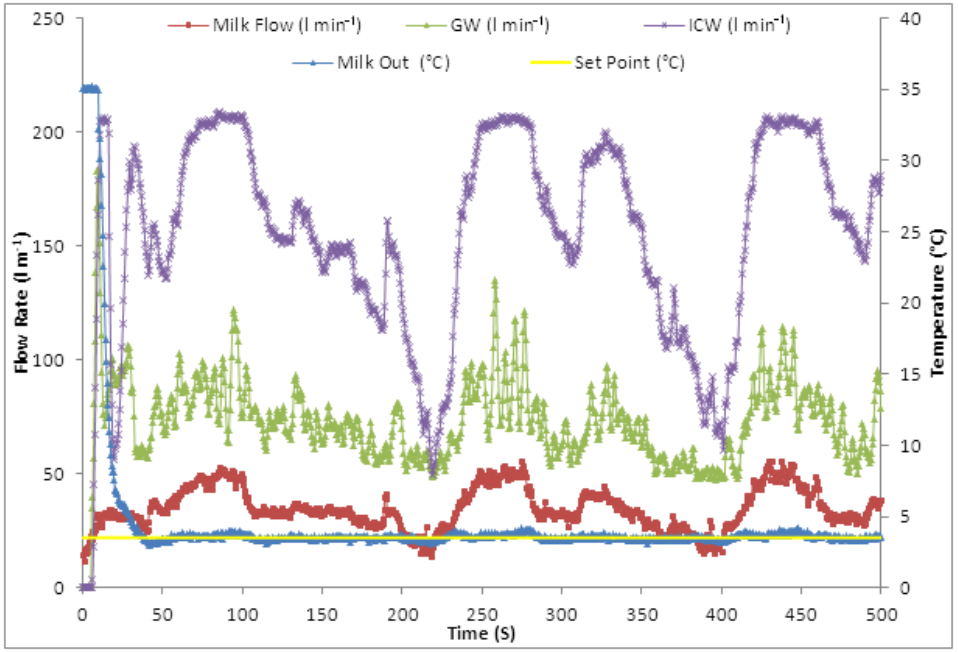
- Feedback (FB) and Feedback-Feedforward (FB-FF) control schemes employed.
- Custom anti-saturation/integral wind-up method developed for variable flow milking machine.
- Eight milk pre-cooling settings (13°C to 20°C, with 1.0 °C increments) used for both controllers.
- Final cooling set point of 3.5°C.
- Energy cost model for varying ground water utilisation.

Controller Comparison Results

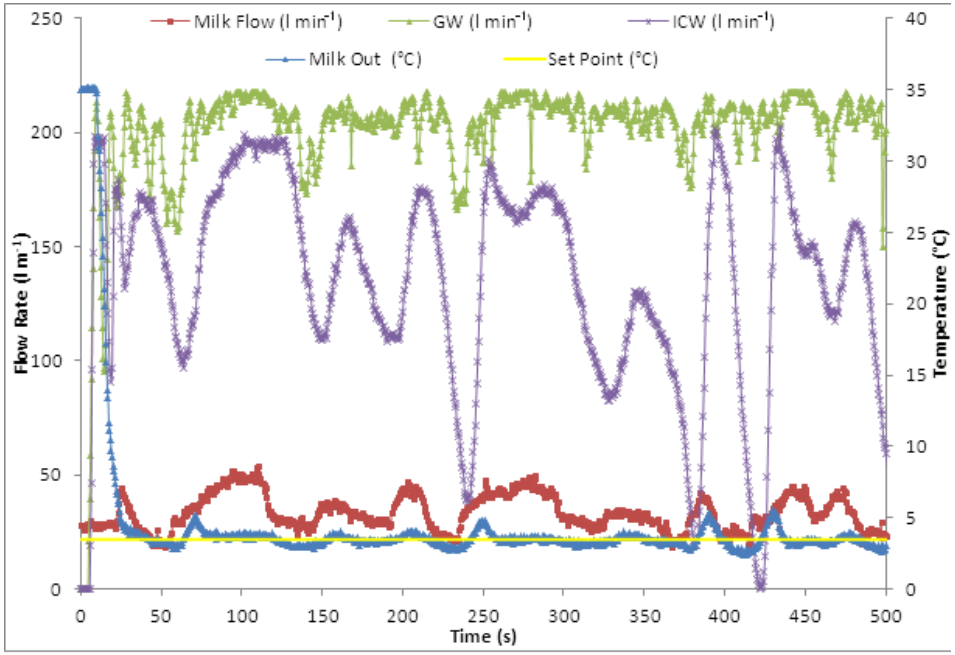
Table 1. Results of the performance indicators for the feedback (FB) controller and feedback-feedforward (FB-FF) controller for eight controller settings (S1-S8).

Control Setting	Min Milk Temp (°C)	Bulk Milk Temp (°C)	Max Milk Temp (°C)	RMSE (°C)	GW Milk Ratio	ICW Milk Ratio
S1FB-FF	2.8	3.5	4.3	0.19	5.90	3.34
S1 FB	2.5	3.6	5.5	0.49	5.98	3.41
S2 FB-FF	3.2	3.5	3.9	0.15	4.44	3.85
S2 FB	2.5	3.5	5.3	0.40	4.54	3.86
S3 FB-FF	2.9	3.5	4.1	0.18	3.36	4.14
S3 FB	2.6	3.6	5.1	0.39	3.38	4.34
S4 FB-FF	3.0	3.5	4.3	0.19	2.92	4.49
S4 FB	2.5	3.7	6.0	0.52	2.97	4.62
S5 FB-FF	2.9	3.5	4.3	0.19	2.68	4.66
S5 FB	2.2	3.6	5.8	0.52	2.69	4.79
S6 FB-FF	3.0	3.6	4.6	0.19	2.46	4.83
S6 FB	2.5	3.7	5.8	0.59	2.51	4.92
S7 FB-FF	2.9	3.6	4.5	0.17	2.19	4.99
S7 FB	2.5	3.7	5.9	0.52	2.21	5.03
S8 FB-FF	2.7	3.6	4.5	0.19	1.98	5.11
S8 FB	2.5	3.7	5.8	0.58	2.02	5.19

Variable Flow Cooling Results

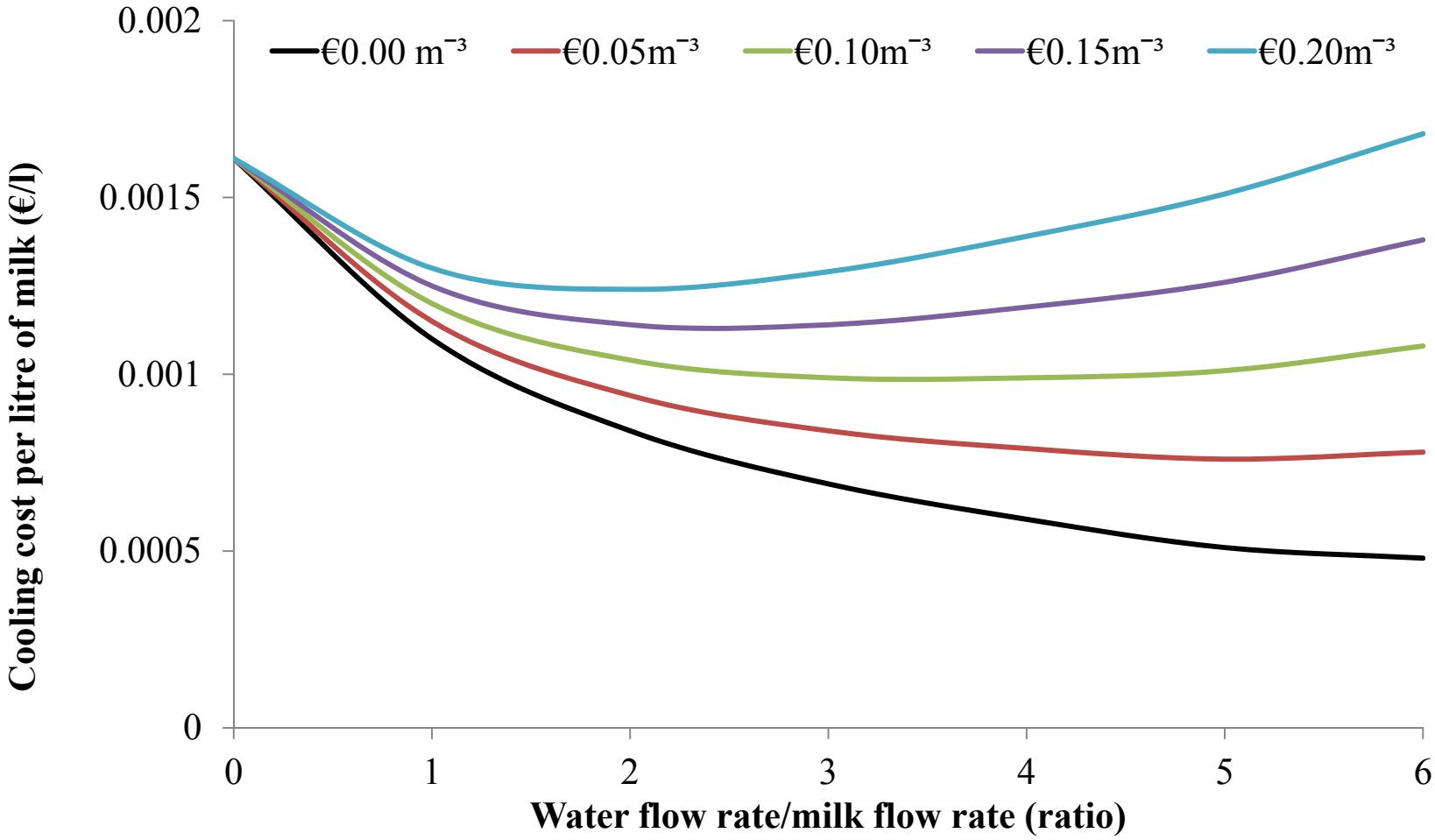


Operating characteristics for feedback-feedforward (FB-FF) controller S8. Flow rates (l min^{-1}) of milk, Ground Water (GW) and Ice Chilled Water (ICW) on left axis. Temperature (°C) of outgoing milk and set-point on right axis.



Operating characteristics for feedback (FB) only controller S1. Flow rates (l min^{-1}) of milk, Ground Water (GW) and Ice Chilled Water (ICW) on left axis. Temperature (°C) of outgoing milk and set-point on right axis.

Varying water cooling costs



Milk cooling cost per litre of milk (€ l/1) with varying water to milk ratios for five different ground water prices

Conclusions

- The rapid milk cooling system is capable of near-instant milk cooling for a variable flow milking machine using controlled quantities of CTES and water.

- The ability to vary water and electricity consumption opens new opportunities for resource optimisation on dairy farms.

References

- CER. 2012. National Smart Metering Programme (NSMP) Information Paper. Commission for Energy Regulation. Dublin.
- DAFF. 2010. Food Harvest 2020. Department of Agriculture Food And Fisheries, Dublin.
- Upton, J., J. Humphries, P.G. Koerkamp, P. French, P. Dillon, I. De Boer (2013). Energy demand on dairy farms in Ireland. Journal of Dairy Science (In Press).

Thank you