Determination of solids and fat contents in bovine milk using a phase-locked resonant cavity sensor

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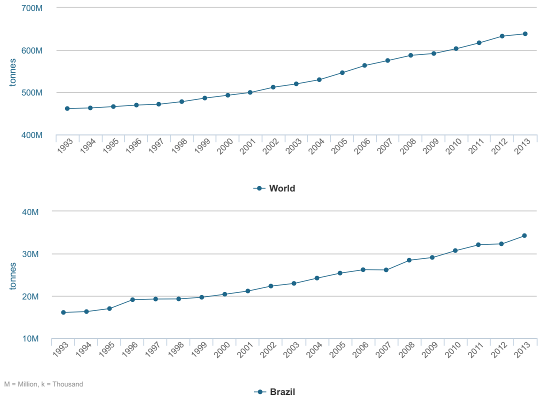
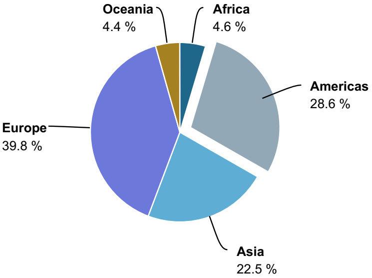
Milk characteristics

- Common food in daily diet.
- Rich source for human nutrition.
- Good effects on growth and recovery from undernutrition.

Proximate composition of cow milk (per 100 g of milk)	
Water (g)	87.8
Total protein (g)	3.3
Total fat (g)	3.3
Lactose (g)	4.7
Ash	0.7

Bovine milk production





[1]

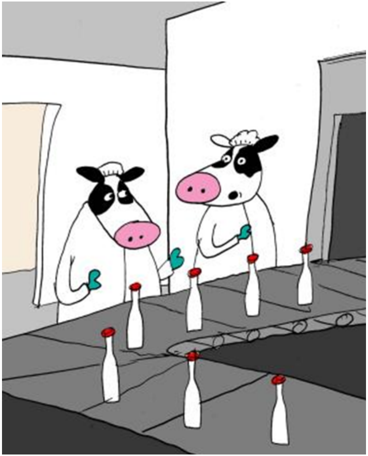
- World production growth $\approx$ 39% - Around 638 Million tonnes (2013)
- Brazil production growth $\approx$ 112% - Around 34 Million tonnes (2013)

[1] Source: Food and Agriculture Organization of the United Nations - Statistics Division

Milk quality monitoring

Motivations

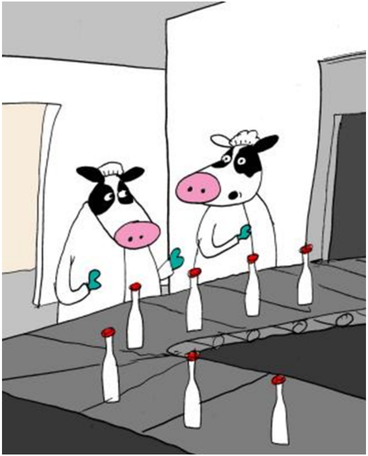
- Characterization of different types of milk.
- Identification of possible adulteration in the composition of milk.
- Selection of raw materials for the production of certain dairy products.



Milk quality monitoring

Issues

- The complexity of the milk composition.
- The high costs and time consuming in the chemical analysis.
- The skilled labor and the large amount of chemical reagent required.
- The high water consumption and waste liquid emissions.



Milk monitoring technologies

Technologies	Application	Main characteristics	Limitations
Electrical impedance (G. Durante, 2016)	Detection of milk adulteration	Various adulterants tests, low cost and low circuit complexity	Invasive method, difficult to identify the type of adulterant, laboratorial sample measurements
Near-Infrared Diffuse Reflection (L. Ribeiro, 2016)	Detection of milk adulteration	Water adulteration tests, maximum uncertainty less than 3%	Complex apparatus, laboratorial sample measurements
Optofluidic Microviscometer (P. S. Venkateswaran, 2016)	Detection of milk adulteration	Water, flour, starch and urea adulteration tests	Difficult to identify the type of adulterant, laboratorial sample measurements
Microwave absortion (D. Agranovich, 2016)	Milk characterization	Well adequate for total solids monitoring	Invasive method, laboratorial sample measurements
Near-infrared spectroscopic (M. Kawasaki, 2008)	Milk quality monitoring	On-line measurements, well adequate for the monitoring of fat, protein and lactose constituintes in an industrial facility	Complex apparatus, expensive system
Resonant Cavity Sensor (K. H. Joshi, 2015)	Milk quality monitoring	Detection of fat contents and spoiled milk, using the magnitude of the transmission signal	Laboratorial sample measurements using a Vector Network Analyzer

This work

Objective

To investigate the feasibility of using a resonant cavity sensor, adequate for industrial facilities, for detecting total solids and fat contents, in real-time using a phase-locked circuit.

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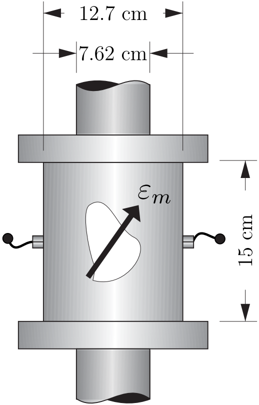
Resonant Cavity Sensor[2]

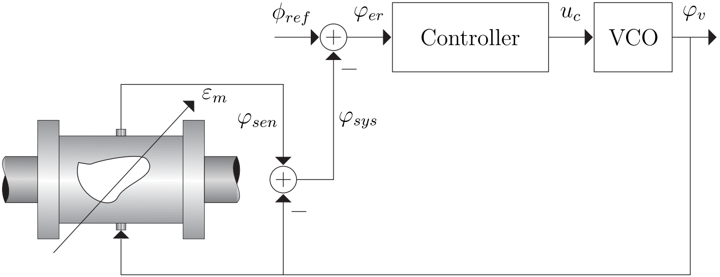


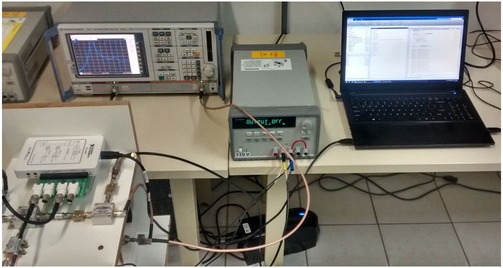
Frequency range [150 - 250] MHz

$$f_o = \frac{k\, c}{\sqrt{\varepsilon_m}}$$

[2] H. E. Avila, D. J. Pagano, and F. R. de Sousa. "Improving the performance of an RF resonant cavity water-cut meter using an impedance matching network". *Flow Measurement and Instrumentation* 43, pp. 14 –22, 2015.

Measurement system setup





Physicochemical analysis and sample preparation

Table: Characteristics of the samples

Samples	Temperature [°C]	Composition [mL]
W	25	2000 W
SS	24.8	2000 SS
S	25	2000 S
A1	24.7	1000 W + 1000 SS
A2	24.5	1000 W + 1000 S
A3	24.5	1000 SS + 1000 S
B1	24.5	1000 A1 + 1000 A2
B2	24.5	1000 A1 + 1000 A3
B3	24.5	1000 A2 + 1000 A3

Physicochemical analysis and sample preparation

Table: Physicochemical composition of the samples.

Samples	Density [$g\,cm^{-3}$]	Titratable acidity [g lactic acid/ 100g]	pH	Total solids [g/100g]	Fat [g/100g]
W	1.031 ± 0.000	0.131 ± 0.003	6.87 ± 0.02	11.50 ± 0.25	3.20 ± 0.00
SS	1.034 ± 0.000	0.128 ± 0.003	6.86 ± 0.01	9.95 ± 0.09	1.20 ± 0.00
S	1.035 ± 0.000	0.131 ± 0.003	6.83 ± 0.02	9.04 ± 0.13	0.10 ± 0.00
A1	1.033 ± 0.000	0.131 ± 0.003	6.81 ± 0.07	10.73 ± 0.15	2.20 ± 0.00
A2	1.033 ± 0.000	0.127 ± 0.003	6.78 ± 0.01	10.27 ± 0.18	1.65 ± 0.00
A3	1.035 ± 0.000	0.126 ± 0.005	6.79 ± 0.03	9.50 ± 0.08	0.65 ± 0.00
B1	1.033 ± 0.000	0.131 ± 0.003	6.80 ± 0.00	10.50 ± 0.16	1.93 ± 0.00
B2	1.034 ± 0.000	0.127 ± 0.003	6.84 ± 0.00	10.11 ± 0.11	1.43 ± 0.00
B3	1.034 ± 0.000	0.128 ± 0.002	6.90 ± 0.01	9.88 ± 0.13	1.15 ± 0.00

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Results and discussion

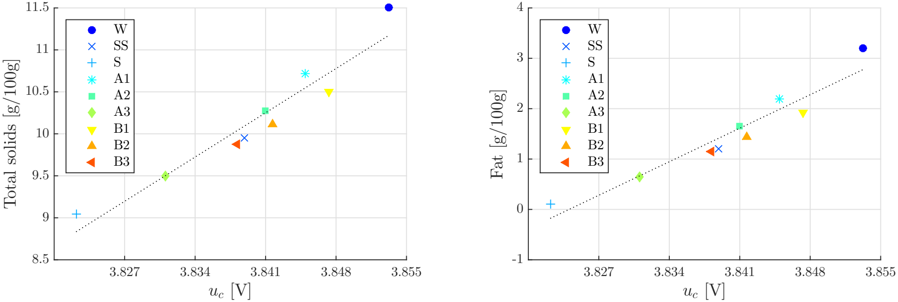

Table: Correlation analysis: milk constituents against u_c [V].

Constituent	**Pearson's coefficient**	**p-value**	**Sensitivity** [g/100g mV]	**y-intercept** [V]	R^2
Total solids	0.961	<0.001	0.0753	3.705	0.9227
Fat	0.959	<0.001	0.0950	3.824	0.9188

$$f_o = \frac{k\,c}{\sqrt{\varepsilon_m}}$$

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- A high correlation and a linear dependence between the system response and the volume fraction of total solids and fat were found.

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- The system allows noinvasive and non-destructive measurements with faster response and simpler installation.
- A high correlation and a linear dependence between the system response and the volume fraction of total solids and fat were found.
- These results allow us to explore other similar applications, such as, the detection of milk adulteration used as raw material in derived dairy products.

Acknowledgments

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That's all folks!

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