Microwave Volumetric Liquid Heating for the Dairy Sector

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1. Introduction

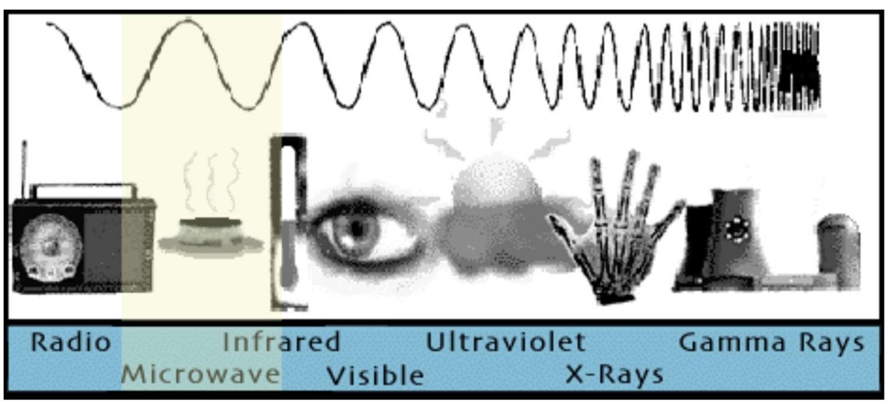
In 1946 when Dr Percy Spence was working at the Raytheon Laboratories in Boston, Mass, he discovered that free microwaves heated the contents of his lunch box, ever since, people have had a fascination of the potential applications for thermal treatment using microwaves.

Microwaves are electromagnetic radiation, produced within a magnetron device built in to a transmitter by using high voltage electricity, ~20,000V circulating within an electro-magnet and then directed through waveguides to the required end point.

For domestic and commercial use, 2.45 GHz and for industrial use 896-915 MHz are the most common frequencies. For the purposes of this abstract, we will concentrate on 896/915 MHz which are approved industrial frequencies.

At 915/896 MHz, microwaves work by oscillating the polar molecules of hydrogen and oxygen in a magnetic field of 915,000,000 or 896,000,000 times per second, they line up with the field. When the field rotates the molecules alternate at the exposed frequency generating heat.

Microwaves are at the median of the electromagnetic spectrum, below UV, X-Rays and Gamma Rays which can alter cell structure and DNA when humans are exposed to them. Microwave will heat materials.



Microwave applicators are shielded to protect the operators working around the equipment.

The applicator will be, in effect a Faraday Cage which is an earthed metal screen surrounding exposed area equipment to exclude electromagnetic influences. Whatever applicator is employed, it must restrict microwave leakage below 5mW/cm^2 measured approximately 300 mm from any opening, joint etc. This level was agreed and ratified globally by the IEEC (International Electro Technological Committee) some years ago.

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2. Research Stage 1~ Pilot Plant Pre-heating ΔT 60º Celsius

The objective of the research for the dairy industry was to significantly reduce energy and water consumption through the processing phase of added value products such as yoghurt, quark and UHT milk.

Scientific and technological research and development was carried out for environmental, economic, social and policy validations during the project, energy savings of at least 20% and water savings of at least 30% were targeted against existing performance data.

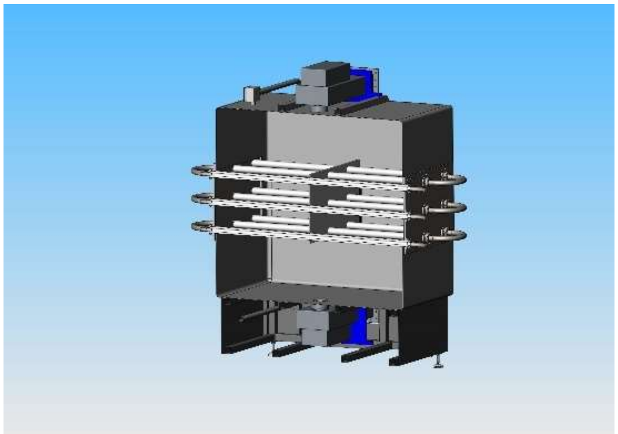
High volumetric liquid heating is normally carried out using heat exchangers with steam, water or electricity as the principle energy source. Steam requires the investment of a boiler, several hours warm up time from cold and frequent maintenance, plus of course gas, oil or bio fuels and water to generate the steam. Electricity, such as used in heater elements is slow reacting and requires a lot of energy to raise temperature. Thus microwave, used in the right way gained a number of advantages such as:

- Instantaneous heating
- Few moving parts
- The energy source can be located next to the production
- Reliability
- Efficiency
- Compactness
- Use of renewable energy (electricity)

Scenarios for the design of the ideal microwave heating resonator or cavity were examined.

The microwave power generated by the transmitter (power source) would be delivered to the cavity via waveguides, (Type WR975) which correspond to the 896/915 MHz frequency band. The cavity would be an approximate cube and the port of entry would be top and bottom directly opposing each other.

The cavity would by polished stainless steel with a smooth interior to allow the maximum effect of reflected energy to remain within the cavity.



Internally was a tube cluster, the position of tubes and location therein was a matter of computer modelling of the microwave distribution for gaining maximum absorption and best heating characteristics.

The type of tube material was researched, Peek, Quartz and PTFE.

Peek and quartz were not necessary for the pilot plant trials as this was a proof of concept only and measuring wasted microwave energy which can be reflected backwards through the waveguides to the power source.

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The arrangement of tubes was designed to allow limited expansion of the PTFE tubes whilst retaining the integrity of the Faraday Cage preventing microwave leakage.

Tests carried out at up to 900l per hour showed that approximately 1.1 kW of microwave energy would raise quark by 1^{0} Celsius.

A pilot plant was designed and built by DanTech (Fig. 1). This shows the microwave cavity with water circulating between the intermediate bulk containers 1 and 2.

Fig.1

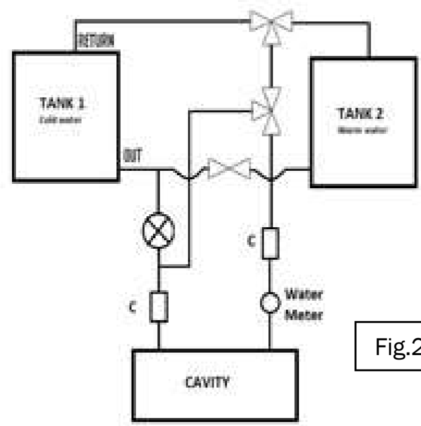

Fig.2

Fig. 2 shows the flow diagram of the mass flow using water as the test medium.

Flow Rate and Temperature change

Product:	H_20			
kW Input	T_1	T_2	ΔT	Mass Flow
40	14.90	48.30	33.40	~900l
50	15.90	58.00	42.10	
60	17.20	71.50	54.30	

When considering how liquids will react to microwaves we have to consider “dielectric properties”. These are the insulating properties that all materials have, which is the ability to absorb or reflect microwaves. Water is a perfect example for a test basis because it is homogenous and of course its molecular properties are H_2O.

When we are heating say quark, the fat content can be from 1 - 40% this range will give a wide range of results that have to be calibrated for optimum results.

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3. Pilot Plant Stage 2 Industrial Application

This stage required full, continuous testing within a factory environment. The project partner, Schwartzwald Milch from Offenburg, Germany was willing carry out long term trials with quark compounds of varying solid matter up to about 38%.

The installation was placed directly in line with the feed of quark to a spray drying tower and monitored first over 31 hours and then over much longer periods.

Fig.4 Microwave Power Supply

Fig.5 Spray Tower

Fig.5 Microwave Resonator

Fig.6 Monitoring Software

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The recorded results showed significant benefits:

- Energy consumption 10% less than steam heating and heat exchangers
- 11% productivity improvement
- Less frequent down time for CIP = More production

Plate or tube heat exchangers require the external surface to be much higher to allow conduction.

As the heat is conducted through the plate or tube it causes fouling. The extent of fouling will depend upon the product.

In one example, a daily manual and semi-automatic CIP clean down took place, the production flow interruption was about 8 working hours.

With the microwave heating, the system was operational for 31 hours, the microwave resonator tubes were dismantled and inspected, there was no hard fouling whatsoever. The microwave process showed that each 72 hours of production, one days' extra production is gained.

In fig. 7, There was no hard fouling on the tube interior, thus no loss of energy.

Fig.7 Tube inspection after 31 hours of continuous operation

3. Design and Build plant 1200 l/h with Heat Regeneration Pasteurizing + Sterilizing

The final project stage was to build a plant capable of reaching temperatures of viscous and semi viscous food products up to 140^{o} Celsius.

The challenge for this process was to re-examine material for the tubes acceptable by the food process industry with minimal linear expansion. PTFE was unsuitable as the linear expansion over ΔT 54 was as much as 30 mm (given a tube length of about 1400 mm).

Quartz glass proved to be the best as it had the lowest linear expansion with less than 0.01 mm at 140^{o} C, and capable of reaching a temperature of 1100ºC.

However, due to the fragility of the quartz tube cluster, a study group involving suppliers and designers was formed to redesign of the seals, supports, clamps and flexible connections between the tubes.

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Conventional Heating -V- Microwave Heating

Reaching more than 140° C would be considered as sterilization thus the entire system would be built to work at this elevated temperature.

It was a very important aspect of the project to recover as much energy as possible, therefore a regeneration system was designed and built according to the flow diagram

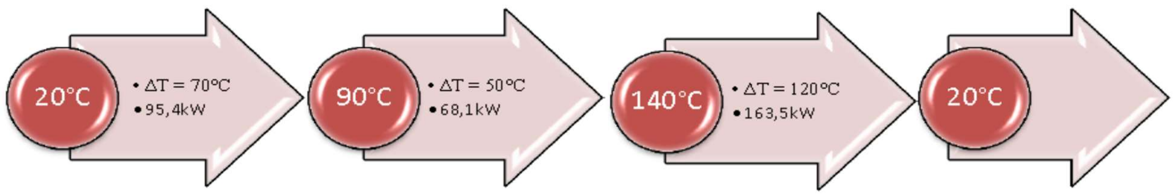

Fig. 8 Conventional system

The scenario for conventional heating and cooling is shown in fig.8. The total power for the energy source that is needed is 33 kW and 6 kW for the pumping system.

The scenario for the volumetric liquid heating by microwaves vastly saves energy. See fig. 9

First process, pasteurizing:
1.1 First heating of product from 20 to 80°C using in counter flow hot water from 85 to 25°C.

1.2 Second heating of product from 80 to 90°C using the first microwave unit.

1.3 The first duration tube ensures that the product maintain its temperature for 20 seconds.

1.4 Second cooling of product from 90 to 30°C using in counter flow cold water from 25 to 85°C.

1.5 Final cooling of product from 30 to 20°C using in counter flow chilled water from 1 to 5°C.

Second process, sterilization:

1.1 First heating of product from 20 to 80°C using in counter flow hot water from 95 to 35°C.

1.2 Second heating of product from 80 to 90°C using the first microwave unit.

1.3 Third heating of product from 90 to 120°C using in counter flow hot water from 130 to 100°C.

1.4 Final heating of product from 120 to 140°C using the second microwave unit.

1.5 The second duration tube ensures that the product maintain its temperature for 5 seconds.

1.6 First cooling of product from 140 to 110°C using in counter flow water from 100 to 130°C.

1.7 Second cooling of product from 110 to 50°C using in counter flow cold water from 35 to 95°C.

1.8 Final cooling of product from 50 to 20°C using in counter flow chilled water from 1 to 8°C.

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Pasteurizer / sterilizer with use of microwave and regeneration of heat.

The system is built regarding food safety standards. The main material is stainless steel grade 1.4301.

The system includes valves, pumps and sensors that are also designed according to these normal standards. These components can be used in different ways per process.

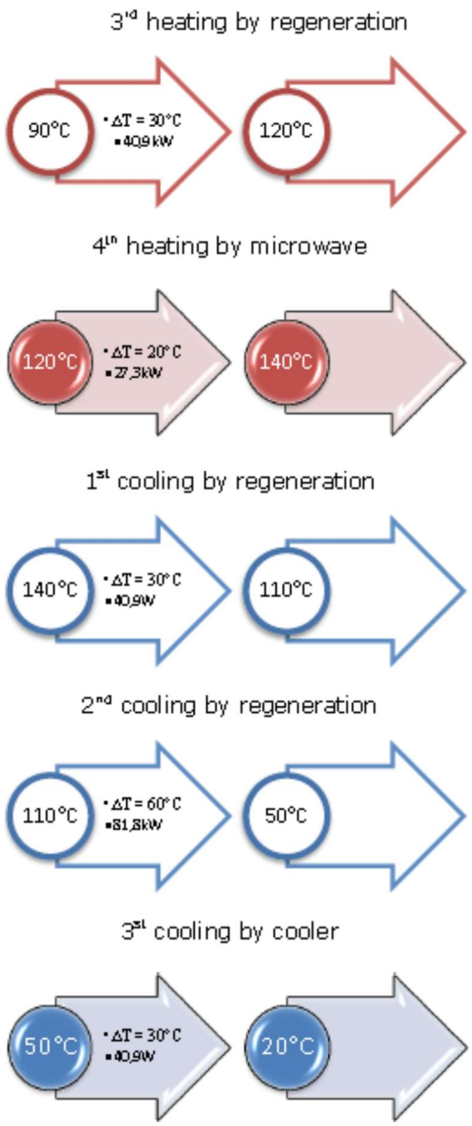

Fig. 9 Heat Regeneration Cycle

The microwave system reuses heat on the both heat cycle and cooling cycle. By doing this, the heat we can save 123 kW on the heating and 123 kW on the cooling cycle, thus making a total energy saving of 73.8%.

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Input

Cold water	2	m3/h		
Elektricity regeneration unit	16	FLA		
Elektricity microwave units	200	FLA		
Ice water	4	m3/h	1	°C
Air pressure	6	bar	40	l/min

Consumption

			In production	When Cleaning
Lobepump	2,20	kW	X	X
Waterpump circuit 1	0,75	kW	X	X
Waterpump circuit 2	0,75	kW	X	X
Centrifugal pump	2,20	kW	-	X
Microwave 1	13,60	kW	X	X
Microwave 2	27,30	kW	X	X
Cooling	40,90	kW	X	-
Total			**85,50 kW**	**46,80 kW**

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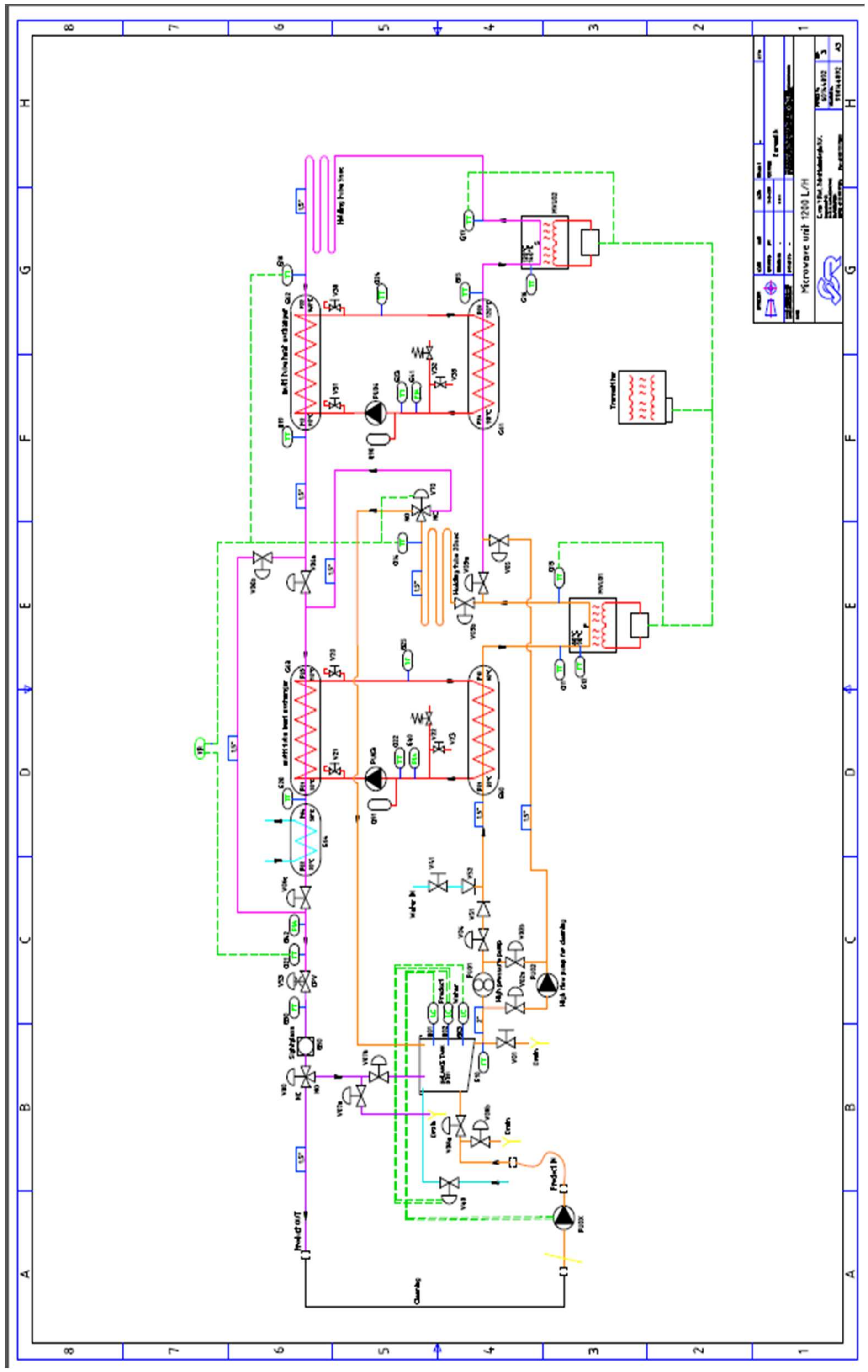
Piping & Instrumentation Diagram (P& ID) for the Process (Fig 10)

Fig. 10 P & ID



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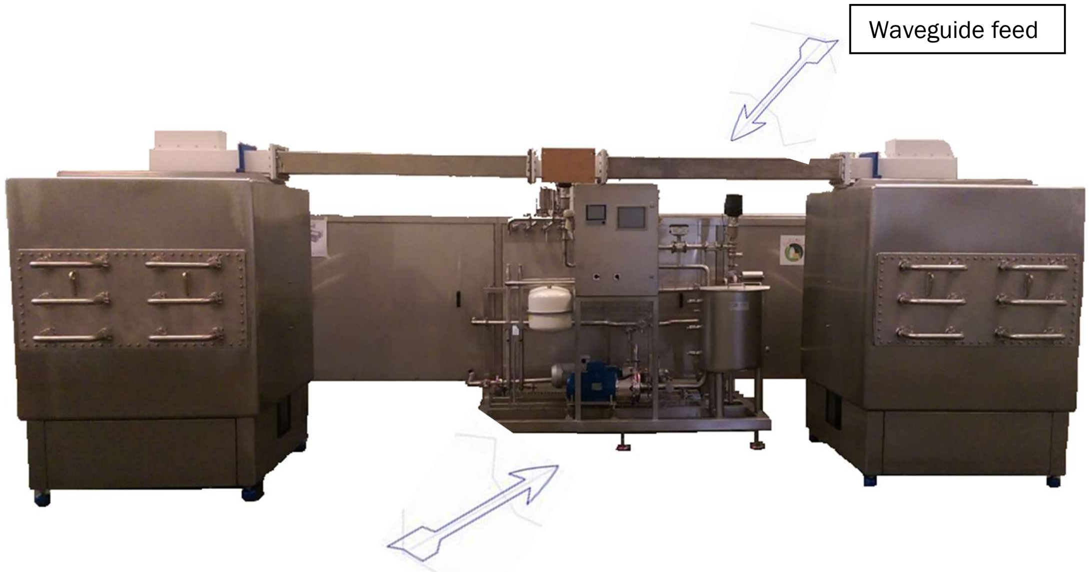
Microwave Twin Resonator System for Pasteurization and Sterilization (Fig. 11)

Shown below are the tandem resonators receiving microwave power from a single 75 kW power supply.

The power supply delivers the microwaves via a system of waveguides, in this case type WR 975 which corresponds directly to the frequencies of 896/915 MHz.

Fig. 11 Twin Microwave Resonators

Waveguide feed



Heat Regeneration Unit

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Conclusions:

The system can be used for viscous and semi viscous food products with a maximum pressure of 5 bar. This is due to the bursting pressure of the quartz tubes.

We have recognised that about 3-5% of the microwave energy can be reflected back to the magnetron. Safety devices are built into the transmitter/power supply in case the reflected power suddenly increases due to a tube blockage or fault.

Therefore, the microwave efficiency is shown as:

- 100% - Reflected Power and operating requirements, such as cooling of the magnetron, typical of 75 - 80% efficiency.

Renewable Energy Utilization:

There is a worldwide demand for less reliance on fossil fuels, this trend will increase, and fossil fuels will be increasingly reserved for transport, emergency services, home heating as well of course the food industry.

Where there is the economic possibility to adapt to renewable energy, microwave technology has the opportunity to be taken up, demonstrating green energy credentials.

Benefits:

Below are a few of the benefits for the system:

- Operational time can gain up to 1 day's production every 3.
- The systems are hygienic and follow all the current material guidelines for CE, USDA and FDA.
- Start-up and shut down times are minutes not hours.
- Control is easy from the HMI panel.
- The system can operate unattended
- Overall investment costs compare favourably against conventional heating methods such as steam, HPP technology (Hyper Pressure Processing)
- The footprint is small, and the equipment can be installed in a production area.
- No change in organoleptic properties can be provided by The University of Hohenheim.
- Extends shelf life.
- Further uses, it is envisioned that apart from the dairy sector, sauces, marinades, gravies, fruit pulp.

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2) University of Hohenheim, Stuttgart

3) Schwartzwald Milch GmbH, Freiberg, Germany

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