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# Design parameters for the separation of fat from natural whole milk in an ultrasonic litre-scale vessel

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ABSTRACT

The separation of milk fat from natural whole milk has been achieved by applying ultrasonic standing waves (1 MHz and/or 2 MHz) in a litre-scale (5 L capacity) batch system. Various design parameters were tested such as power input level, process time, specific energy, transducer–reflector distance and the use of single and dual transducer set-ups. It was found that the efficacy of the treatment depended on the specific energy density input into the system. In this case, a plateau in fat concentration of ~20% w/v was achieved in the creamed top layer after applying a minimum specific energy of 200 kJ/kg. In addition, the fat separation was enhanced by reducing the transducer reflector distance in the vessel, operating two transducers in a parallel set-up, or by increasing the duration of insonation, resulting in skimmed milk with a fat concentration as low as 1.7% (w/v) using raw milk after 20 min insonation. Dual mode operation with both transducers in parallel as close as 30 mm apart resulted in the fastest creaming and skimming in this study at ~1.6 g fat/min.



## 1. Introduction

A technique using ultrasound waves to initiate separation of fat globules from a recombined milk-fat emulsion has been recently reported by Juliano et al. [1,2]. Milk fat globules move to the pressure anti-nodes, due to a time-averaged primary radiation force described, for instance, in Yosioka and Kawasima [3]. Enhanced flocculation (reversible combination) or coalescence (irreversible combination) of the fat droplets may occur at these sites [4]. This increases the effective floccule size of the fat globules, and cause a faster rise velocity and hence separation speed [5].

Enhanced creaming of re-emulsified fat orders of magnitude faster relative to natural buoyancy was reported on a litre-scale [1]. On a micro-scale, Grenvall et al. [6] and Johansson et al. [7] showed that acoustic waves could be used to specifically remove fat globules from skim-milk. To the best of our knowledge, no study has yet reported the use of ultrasound to achieve enhanced separation of fat globules from 'natural' whole milk, with particle size distributions and interfacial properties typical of the native product on a litre-scale.

Successful trials using natural whole milk have notably only been reported in smaller-scale experiments [2]. Trials using the same parameters as those reported by Juliano et al. [1] to separate fat from natural whole milk on a litre-scale were unsuccessful (data reported in Thesis by Sandra Temmel, University of Erlangen [8]).

The reason for this is because the model emulsion system investigated by Juliano et al. [1] and natural whole milk are fundamentally very different. Firstly, the particle size distribution of the recombined milk emulsion used by Juliano et al. [1] is significantly different to those found in natural milk. The volume weighted mean diameter, $D$ (4,3), of the initial emulsions used by Juliano et al. were reported to be 23 μm. This is significantly larger than those used found in 'natural' milk, which are typically between 3–4 μm [5]. There are also a significant number of globules in the size range of 10–30 μm found in the recombined emulsions studied (see Fig. 2 from Juliano et al. [1]). As noted by Mulder and Walstra [5], even a small number of 'large-globules' present in milk, can make up about 2–3% of the total fat of the milk sample. Because the occurrence of these large globules in the recombined milk emulsion used by Juliano et al. is high, there is a skew of the percentage of total fat that is represented by large globules in the model system [1].

In ultrasound separation, the size of the globules plays a significant role in how easily they can be manipulated by the applied ultrasound and also how strongly they are influenced by sedimentation/buoyancy. The primary radiation force scales with the radius to the third power [3]. This means that a globule with a radius of

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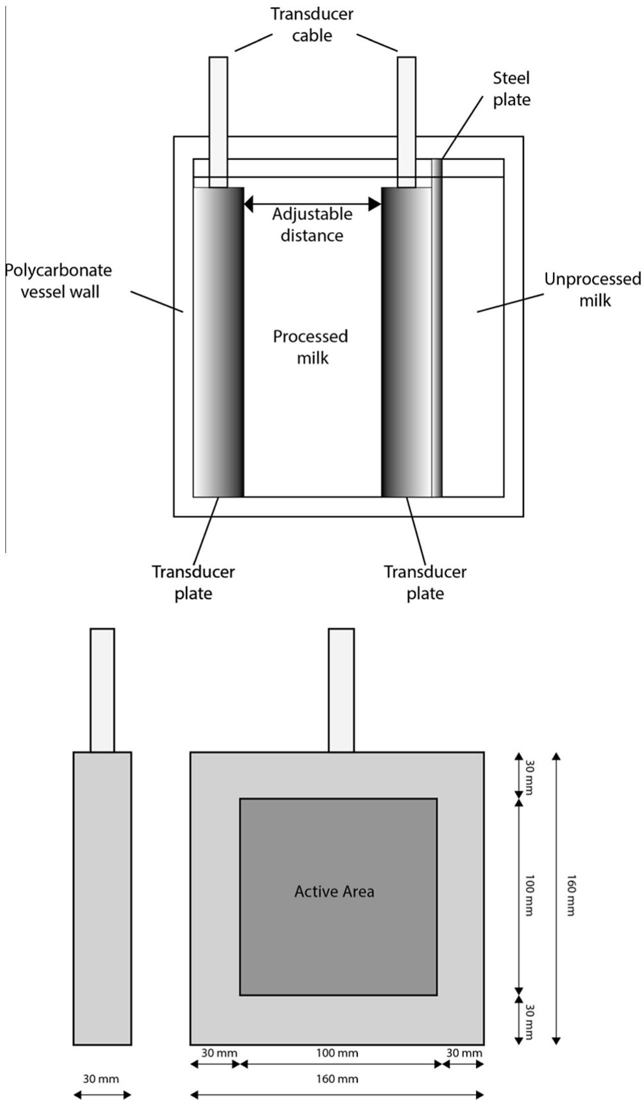


**Fig. 1.** Schematic of the experimental set-up for batch mode operation for raw milk fat separation. The adjustable distances between the two transducer plates considered in the experiments are 30 mm, 45 mm, 85 mm and 135 mm.

10 μm is approximately 125 times more strongly influenced by the ultrasound than a globule that is 2 μm in radius. Since a high proportion of the fat is represented by these larger globules, the recombined milk emulsion as studied by Juliano et al. [1] is significantly easier to separate with ultrasound than 'natural' whole milk.

Secondly, the interfacial surface properties of the recombined milk emulsions and 'natural' milk, are completely different. In 'natural' milk, the fat globules are stabilised by a complex membrane layer consisting of primarily a tri-layer of phospholipids and proteins [5]. The nature of this surface prevents coalescence from readily occurring. By contrast, a 'recombined' milk emulsion does not have such a stabilising barrier. Instead, it is surrounded by casein micelles and other milk proteins that self-assemble on the surface [9]. Evidence of significant coalescence was observed upon application of ultrasound in the study by Juliano et al. using the recombined milk emulsion. It is uncertain if coalescence will occur readily in 'natural' milk systems when using high frequency ultrasound for the purpose of separation, but its absence would mean that rapid separation would be more difficult to achieve.

Further intensification of the process is necessary to achieve separation in 'natural' milk systems. Hence, this present study aims to establish the parameters that are suitable for separation of 'natural' whole milk on a litre-scale. Such a study could have significant practical relevance to the dairy industry.

An obvious strategy to speeding up the fat separation rate is to increase the acoustic power input or the frequency. According to the primary radiation force described in [3], this would result in a stronger acoustic force and likely result in more effective fat separation. However, it has been previously noted that achieving effective separation is not so simple as increasing the power, because effects such as acoustic streaming must also be considered [10]. Strong streaming velocities may disrupt the separation effectiveness by preventing globules from collecting at the pressure anti-nodes.

This current study investigates the efficacy of intensifying the specific energy density on the separation of fat from 'natural' milk systems by modifying the vessel geometry, the use of different frequency operation modes and adjusting the duration of ultrasonic insonation.

## 2. Materials and methods

### 2.1. Ultrasonic separation trials

Raw whole bovine milk was sourced directly from the farm (Department of Primary Industries Ellinbank, Australia) and used for separation tests within 24 h of obtainment. Milk was maintained at refrigerated temperatures during transportation and was stored in a cool-room at approximately 4 °C prior to usage. All trials were performed with reference to an initial starting

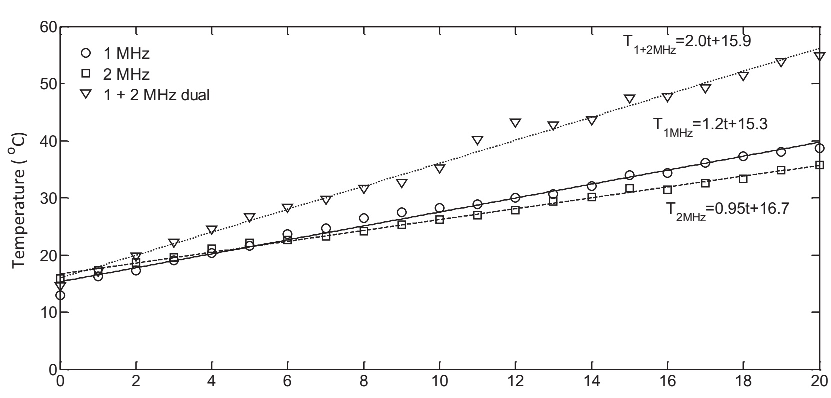


**Fig. 2.** Temperature change in the vessel with application of 1 MHz (330 W), 2 MHz (290 W) and 1 + 2 MHz (620 W) dual frequency with a transducer–reflector distance of 45 mm (processing volume of 1.6 L).