

Scouring of Sheep Wool Using an Acoustic Ultrasound Wave

DOI: 10.5604/01.3001.0015.2721

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Abstract

The paper describes a method of scouring sheep wool using ultrasound. The inspiration to start work on the use of ultrasound in the process of scouring sheep wool was positive results that had already been achieved for alpaca wool. Due to the fact that sheep wool has many more impurities than alpaca wool, the scouring process is divided into two stages. The first involves the removal of faeces from the wool, which may be up to about 35% of the impurities of sheep wool, while the second stage involves the scouring cycle, wherein the remaining impurities are removed. The ultrasonic scouring process uses domestic merino wool heavily clad, particularly, by faeces. In this study, detergent solutions, alkali soap and sodium carbonate were used. The scouring of wool was carried out with a special apparatus equipped with an ultrasonic generator, at a frequency of 40 kHz. To determine the optimal conditions for scouring sheep wool that could affect the amount of impurities removed, the following parameters were examined: the effect of the scouring time, the concentration of detergents, and the scouring bath ratio. The study resulted in achieving optimal scouring parameters that ensured a satisfactory level of the removal of wool impurities.

Key words: sheep wool, wool scouring, ultrasounds, scouring agents, impurities of wool.

Well-known and widely used devices for the scouring of greasy wool are the so-called “leviathans” [1, 2]. This machine consists of several tanks connected in one technological process line and is equipped with conveyors (forklifts, harrowing). The scouring baths comprise a solution of soap and sodium carbonate. Scouring is carried out in such a way that the loose fibre wool is transferred by the conveyors from the first bath into another bath and then in a countercurrent to the scouring bath. This system of scouring, used for a long time, has several drawbacks, among which there is the large production space required, as well as relatively low scouring efficiency, large quantities of energy and water consumption needed, and the problem of sewage disposal.

In recent years there has been a dynamic development of ultrasonic techniques in various industries, including the textile industry [1-15]. Ultrasonic technology in the textile industry is mainly used in wet textile processes: desizing, degumming scouring, bleaching etc [1-15].

One of the more common applications are ultrasonic washing machines. Physical phenomena occurring during ultrasonic cleaning are cavitation, acoustic wind and radiation pressure [5]. Cavitation is the formation of liquids in very small vacuum bubbles, with the pulsations and implosion occurring when the liquid is subjected to a variable pressure.

It may be produced by ultrasonic waves, provided that they have the appropriate frequency and intensity. In the world the use of ultrasonic waves in wet textile processes – especially in dyeing and washing processes have been known for more than 20 years [5-8].

The idea of implementing ultrasonic energy to textiles has been around since the 1990's. Ultrasonic energy was generally applied to textile dyeing and finishing processes [17-18]. Cotton materials can be bleached [19] and stains on surgical gowns [20] can be easily removed with the use of ultrasonic energy. Fabrics treated with ultrasonic waves showed less tenacity loss than in the conventional methods [20]. Ultrasonic energy was also applied [21] to the dyeing of woven wool fabric. Ultrasonic energy allows for process acceleration and the attainment of the same or better results than by existing techniques under less extreme conditions, i.e., lower temperature and lower chemical concentrations [22]. Textile wet processes assisted by ultrasonic energy are of high interest for the textile industry for this reason.

Pan et al. [23] investigated the ability of low temperature wool dyeing after ultrasound assisted pretreatment. They observed a significant increase in the colour strength and dye uptake after ultrasound assisted wool pretreatment. Kadam et al. [24] investigated wool fibre damage after the ultrasonic assisted scouring process.

■ Introduction

Raw sheep wool is contaminated with a large number of impurities, such as plant parts, mineral impurities, sweat, grease and faeces. The amount of contaminants depends on the type of wool as well as on the living conditions of the animal. Wool contaminants must be removed before yarn processing and are mainly removed using mechanical, physical-chemical and chemical methods.

Ultrasonic scouring of wool fibres do not affect the properties of wool. Research showed that ultrasonic support of the process with a reduced chemical amount, time and temperature allows to effectively grease removing. In the research of Peila at al. [25], in ultrasound assisted scouring processes of cotton and wool fabrics, temperature plays a crucial role for the intensification of ultrasound cavitation. Better results can be achieved at lower temperature and for a short process time. Bahtiyari and Duran [26] found that three-step ultrasound assisted washing of wool gives nearly the same results as five-step conventional wool washing. Czaplicki and Ruszkowski [7-8, 22] determined optimal conditions for ultrasonic assisted scouring of alpaca wool. They found that ultrasonic-assisted alpaca wool washing resulted in shortening the washing time as well as a reduction in water, energy and detergent consumption. Braniša et al. [27] compared the ultrasound-assisted scouring of sheep wool using water and water with commercial detergent for extraction using dichlorometane. The results showed, that ultrasonic-assisted scouring with water without the addition of detergent is comparable to detergent scouring and the extraction method of selected metal sorption, but with a lower removal of wool impurities.

The aim of this work was to develop optimal conditions for the ultrasound assisted scouring of sheep wool, including wool heavily contaminated with faeces. It was assumed that the effect of the acoustic ultrasound wave would help to reduce the consumption of water and detergent, as well as the washing time.

Material and methods

Materials

Merino sheep wool was received from sheep breeding in Poland. Potassium soap, sodium carbonate and Septifos Vigor were used without further purification. The characteristics of raw wool are presented in *Table 1*. All samples of sheep wool were stored in a climatic chamber (temperature 20 °C, humidity 65%) for 24 hours before testing of basic parameters. The basic parameters of raw wool were determined in a certified laboratory according to the standard procedures.

Ultrasonic scouring device

The laboratory ultrasound scouring installation used was based on a Sonic-14

Table 1. Basic parameters of sheep wool before scouring.

Breed of sheep	Fibre length, mm	Breaking strength, cN	Elongation at break, %	Fibre diameter, µm	Tenacity, cN/tex	Content of wool fat, %
Merino wool	82	9.1	36.8	26.2	10.8	16.1

ultrasonic scouring device, produced by Polsonic [28]. The device consists of a 14 dm³ chamber, bath heating system (working temperature from 30 °C to 80 °C), and bath drain valve. The ultrasound was generated at 40 kHz frequency with an ultrasonic power of 2×400W. For the experiment on a laboratory scale, the device was equipped with a loading basket made of steel wire. The basket was covered with glass fabric with a 4×4 mm mesh.

Scouring process

The scouring process consists of two steps:

- First step – removing of faeces from greasy wool,
- Second step – ultrasound assisted washing processes.

Removing faeces from greasy wool (first step) was performed in a bath containing 1 g/dm³ of Septifos Vigor (biological activator) for approx. 72 hours, at room temperature and a liquor ratio of 20:1. After dipping with a biological activator, the wool was subjected to centrifugation. Next, it was rinsed in cold water for 10 minutes and subsequently ultrasonically treated at a liquor ratio of 40:1. The dipping bath can be used repeatedly with a small addition of the Septifos Vigor preparation.

Ultrasonic assisted washing processes (second step) were performed in a bath containing soap and sodium carbonate at a liquor ratio from 20:1 to 60:1. Wool fibres were washed with a constant bath level of 12 dm³. The weighed wool fibres placed in a net laundry bag were immersed in the washing bath. Washing of the wool fibres in the net laundry bag allowed to remove more easily as well as the pressing of excess bath volume. The basic washing time for most of the samples was 20 minutes. After washing, the wool was removed from bath, squeezed to remove excess bath water, and then centrifuged. Next, the wool fibres were twice rinsed in water at a temperature of 35 °C for 5 minutes and then dried at room temperature until a constant weight was obtained. The washing process was performed at a temperature

of 35 °C. All rinsing processes were assisted with an ultrasonic wave. Centrifugation of the wool was performed using a Światowid centrifuge. The temperature of the washing bath was controlled with a mercury thermometer within the range of 0-100 °C.

The effectiveness of the ultrasonic assisted washing process for the quantity of fat impurities removed was assessed taking into consideration:

- the effect of the liquor ratio from 20:1 to 60:1 in a bath containing 3 g/dm³ of soap and 2 g/dm³ of sodium carbonate for 20 minutes,
- the effect of the washing time from 10 minutes to 40 minutes in a bath containing 3 g/dm³ of soap and 2 g/dm³ of sodium carbonate and a 60:1 liquor ratio,
- the effect of the washing agent concentration in a bath with a soap content from 2 g/dm³ to 8 g/dm³ and sodium carbonate content from 1 g/dm³ to 4 g/dm³, for a time of 20 minutes and liquor ratio of 60:1.

The efficiency of the scouring process was controlled by the weight method. The mass of impurities removed from the wool was equal to the difference between the mass of the sample before treatment and that after treatment. The masses of removed faeces (M_F), fat and sweat (M_{FAT}) as well as total impurities (M_T) were calculated according to *Equations (1), (2) and (3)*, respectively:

$$M_F = M_R - M_1 \quad (1)$$

$$M_{FAT} = M_1 - M_{1+2} \quad (2)$$

$$M_T = M_R - M_{1+2} \quad (3)$$

where:

- M_F – mass of faeces removed during the first step of scouring, g;
- M_{FAT} – mass of fat and sweat removed after the second step of scouring, g;
- M_T – mass of total impurities removed during scouring, g;
- M_R – raw sample mass, g;
- M_1 – sample mass after the first step of scouring, g;
- M_{1+2} – sample mass after the first and second step of scouring, g.

Table 2. Results of faeces content in greasy wool.

Sample No.	Mass of raw sample, g	Mass of sample after process, g	Mass of faeces removed, g	Content of faeces in sample, %
	M_R	M_1	M_F	P_F
1	200.6	143.1	57.5	28.7
2	200.8	142.1	58.7	29.2
3	200.5	138.2	62.3	31.1
4	200.4	141.2	59.2	29.5
5	200.3	140.1	60.2	30.1
6	200.7	142.3	58.4	29.1
7	200.6	141.2	59.4	29.6
8	200.8	135.5	65.3	32.5
9	200.5	142.1	58.4	29.1
10	200.6	132.2	68.4	34.1
11	200.7	134.4	66.3	33.0
12	200.6	131.3	69.3	34.5
13	200.8	133.5	67.3	33.5
14	200.9	137.6	63.3	31.5
15	200.4	140.1	60.3	30.1
Average	200.6	138.7	62.4	31.1

The percentage content of faeces (P_F) and the content of the total impurities (faeces, fat and sweat) (P_{FAT}) and of fat and sweat (P_T) removed from the wool during treatment were calculated according to *Equations (4), (5) and (6)*, respectively:

$$P_F = \frac{M_R - M_1}{M_R} 100\% \quad (4)$$

$$P_{FAT} = \frac{M_1 - M_{1+2}}{M_1} 100\% \quad (5)$$

$$P_T = \frac{M_R - M_{1+2}}{M_R} 100\% \quad (6)$$

where:

P_F – percentage content of total impurities %;

P_{FAT} – percentage content of fat and sweat %.

P_T – percentage content of the impurities %.

The mass of fibres before and after scouring was determined using a “Radwag” laboratory scale (weighting capacity 250 g and weighting precision 0.001 g).

Results and discussion

Removal of faeces from greasy sheep wool

In order to evaluate the effectiveness of the faeces removal, raw wool was dipped in a bath containing the biological activator Septifos Vigor. The product provides immediate action and long-lasting and balanced biological activity. The results of faeces removal from greasy wool are shown in *Table 2*. The study included 15 samples of greasy wool from different places on the fleece.

Impurities generated by faeces account for up to 31% of the mass of greasy wool. This causes an excessive consumption of detergents and extends the scouring time. In view of these drawbacks, the process of scouring was separated into two stages. i.e. the removal of faeces and a proper scouring cycle. The biological process of transformation that occurs with the use of the bacteria leads to the conversion of solid impurities and fat into water. It runs as follows:

- decanting – separation of the particles. Heavy particles sink to the bottom. The light remain in the upper part,
- liquefying – the contents are liquefied by enzymes and bacteria,
- release – the result of the process is volatile. Odourless gases. Water and a certain amount of minerals.

The ultrasonic assisted washing process

Ultrasound waves are generated in a piezo-ceramic transducer and they penetrate the scouring bath in a bathtub. Variable waves of high and low pressure at a frequency of 40 kHz are formed. In a state of low pressure, millions of vacuum bubbles are formed, which is the process of cavitation development [4]. However, in a state of high pressure, these bubbles implode and release a huge amount of energy. These implosions act as a series of small, cleaning brushes. They propagate in all directions, act on all surfaces and penetrate the scouring fibres.

During the mechanical action on the wool in the baths at an elevated temperature, especially in alkaline environments, the fibres move in the opposite direction to the orientation of the scales, which causes mutual hooking of the filaments and the formation of a dense structure with a masked weave (wool felting). In order to prevent wool felting, all washing processes were carried out at a temperature of 35 °C.

Results of the investigation of the influence of the liquor ratio on the effectiveness of the removal of impurities from raw wool are shown in *Table 3*.

Based on the results of the influence of the liquor ratio on the quantity of fat removal, it can be concluded that the liquor ratio plays a crucial role in the ultrasound assisted washing process. Depending on the liquor ratio used, in the second step of scouring process, ca. 10% (liquor ratio 60:1) to ca. 5% (liquor ratio 20:1) of fat

Table 3. Effect of the liquor ratio on the quantity of impurities removed.

Mass of raw sample, g	Mass of sample after faeces removal, g	Mass of sample after scouring, g	Total mass of impurities, g	Content of total impurities, %	Content of fat and sweat, %	Liquor ratio
M_R	M_1	M_{1+2}	M_T	P_T	P_{FAT}	
200.6	150.2	135.2	64.8	25.1	10.0	60:1
300.2	214.2	193.1	106.9	28.6	9.8	40:1
400.8	277.9	250.5	149.5	30.6	9.9	30:1
500.5	360.4	346.2	153.8	28.0	3.9	24:1
600.4	442.9	422.0	177.9	26.2	4.7	20:1

and sweat are removed from the wool fibres. In order to increase the efficiency of fat and sweat removed from greasy wool during the ultrasound assisted washing process, the washing step should be performed at a 30:1 liquor ratio at least (the best 60:1 liquor ratio).

Results of the investigation of the washing time's influence on the effectiveness of fat removal from raw wool are shown in **Table 4** and **Figure 1**.

Results of the influence of the washing time on the quantity of fat and sweat removed showed that increasing the scouring time has little effect on the quantity of impurities removed. The fat and sweat removal from raw wool ranged from ca. 10% for 10 minutes treatment to ca 12% for 40 minutes treatment. The optimum time of ultrasound assisted raw wool scouring is 20 minutes.

The influence of soap and sodium carbonate concentration in the bath on the quantity of fat and sweat removed was tested. Results of the investigation of the effectiveness of scouring agent concentration in removing the impurities from raw wool are shown in **Table 4** and **Figure 2**.

Based on the results of the effect of the concentration of scouring agents on the quantity of fat and sweat removed, it can be concluded that increasing the concentration of soap and sodium carbonate in the bath increases the effectiveness of impurities removal from wool. The fat and sweat removal from raw wool ranged from ca. 8% to ca 13% for a concentration of soap and sodium carbonate in the bath from 2 g/dm³ and 1 g/dm³ to 8 g/dm³ and 4 g/dm³, respectively. With increasing of the detergent and alkalinity of the bath, the percentage of fat and sweat removal from raw wool increases. Due to wool's tendency to felt during treatment in alkaline conditions and at elevated temperature, the optimum concentration of scouring agents are 5 g/dm³ of soap and 3 g/dm³ of sodium carbonate.

The basic parameters of sheep wool after the ultrasound assisted scouring process are given in **Table 6**.

Almost 14% of the total fat (**Table 1** and **Table 2**) was removed from raw wool fibres after the ultrasound assisted scouring process. No significant decrease in the breaking strength or elongation at break were observed after the scouring process.

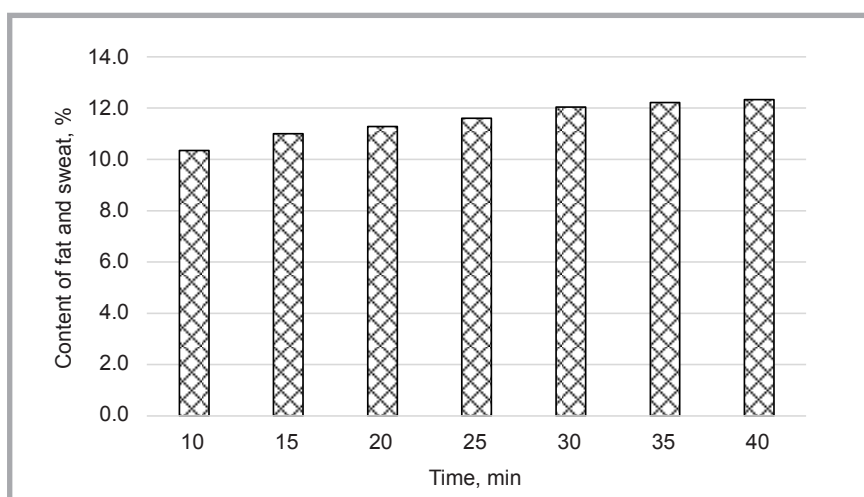


Figure 1. Effect of scouring time on the quantity of impurities removed.

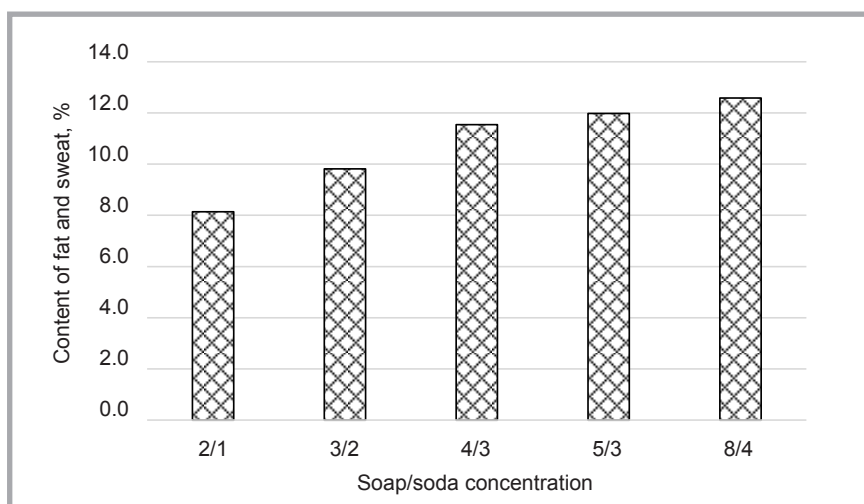


Figure 2. Effect of the concentration of scouring agents on the quantity of impurities removed.

Table 4. Effect of the scouring time on the quantity of impurities removed.

Scouring time, min	Mass of sample after faeces removal, g	Mass of sample after scouring, g	Mass of fat and sweat, g	Content of fat and sweat, %
	M ₁	M ₁₊₂	M _{FAT}	P _{FAT}
10	143.1	128.3	14.8	10.3
15	138.2	123.0	15.2	11.0
20	140.1	124.3	15.8	11.3
25	142.3	125.8	16.5	11.6
30	142.1	125.0	17.1	12.0
35	137.6	120.8	16.8	12.2
40	141.2	123.8	17.4	12.3

Table 5. Effect of the concentration of scouring agents on the quantity of impurities removed.

Scouring agents: soap/sodium carbonate (g/dm ³)	Mass of sample after faeces removal, g	Mass of sample after scouring, g	Mass of fat and sweat, g	Content of fat and sweat, %
	M ₁	M ₁₊₂	M _{FAT}	P _{FAT}
2/1	141.2	129.7	11.5	8.1
3/2	135.5	122.2	13.3	9.8
4/3	142.1	125.7	16.4	11.5
5/3	134.4	118.3	16.1	12.0
8/4	133.5	116.7	16.8	12.6

Table 6. Basic parameters of sheep wool after scouring.

Breed of sheep	Fibre length, mm	Breaking strength, cN	Elongation at break, %	Fibre diameter, μm	Tenacity, cN/tex	Content of wool fat, %
Merino wool	81	8.9	36.2	25.8	10.4	2.2

The fat content in the wool fibres after the ultrasound assisted scouring process is ca. 2%, which ensures a proper touch of fibres.

Summing up

A significant modification of the ultrasound assisted wool scouring process compared to the traditional scouring method is presented in the paper. In the scouring of sheep wool with the use of ultrasound, a significant modification, as compared to the traditional scouring methods, was introduced. The use of an additional operation to remove faeces allowed to reduce the scouring time from several hours to approx. 30 min. The operation for removing faeces from wool is a static process and does not require energy input. The bath wherein the process is carried out is used frequently, contributing to the development desired bacterial flora. Another saving option applied in the scouring process was the introduction of the centrifugation of wool from every technology bath. The intermediate centrifugation of wool from the technological bath also contributed to the mechanical detachment of dirt particles and the removal of them from the fibre. Centrifuging does not damage the material or its felting. Both solutions applied together with the ultrasonic wash system are a source of measurable financial savings and protect the scoured fibre against mechanical damage.

The optimal way to scour wool ultrasonically is as follows:

- removing the faeces from wool is performed in a 1 g/dm³ solution of Septifor Vigor for 72 hours at a 20:1 liquor ratio,
- centrifugation,
- rinsing in cold water for 10 minutes with the use of ultrasound at a liquor ratio of 40:1,
- centrifugation,
- scouring in a bath containing 5 g/dm³ of soap and 3 g/dm³ of soda. In the case of highly contaminated raw material, it is recommended to apply a bath containing 8 g/dm³ of soap and 4 g/dm³ of soda. The scouring time is 20 minutes with the use of ultrasound,

- at a temperature of 35 °C and liquor ratio of 60:1,
- centrifugation,
- rinsing in water at 35 °C for 5 min at a liquor ratio of 40:1,
- centrifugation,
- ultrasound assisted rinsing in water at 35 °C for 5 min at a liquor ratio of 40:1,
- centrifugation,
- drying at room temperature to a constant weight.

The above diagram of performing the scouring operation includes the proposed optimal way of scouring greasy sheep's wool with the use of ultrasonic devices.

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Received 12.04.2021 Reviewed 16.06.2021