PROJECT FINAL REPORT

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1. FINAL REPORT

4.1 Final publishable summary report

Executive summary

The development and construction of a shockwave prototype for the continuous treatment of meat has been accomplished during the project. The novel prototype is the integration of updated shockwave technology concepts considering generation principles and optimal design. Emphasis was put during the project on the study of pressure distribution of the shockwave which represents specific how-know on equipment development and optimization of this particular technology as well as on the mechanical configuration of specific parts included in the shockwave prototype in order to make them more functional and resistant. The prototype provides significant advances in comparison to the former prototype developed by DIL in the nationally funded project (AiF 15884 N). These advantages are mainly a continuous treatment, avoiding the load and unload of explosives or metal wires between the discharged electrodes, and an improved focussing of the shockwaves. However, the development of the prototype has been a very challenging task and still requires further development to become an industrial reality. Especially the optimization of the interaction "machine - meat package" has to be investigated further in order for the shockwave technology to become a more robust application limiting packages with leaks during processing and improving further the tenderization effect. The safety procedures put in place guarantee a safety operation although the high acoustic impact advice for a physical separation from the processing line.

The evaluation of shockwave-resistant packaging materials has been undertaken by a benchmarking study and new developments. The tests with the shockwave prototype showed that, at the moment, there is no commercial packaging material in the European market available. The bags developed by Scheyer and OFI, ESB-L560 with a thickness of 105µm as well as the bag V-9100 with a thickness of 141µm showed the best performance during shockwave treatment relating to stability and seal bond strength, but the bag V-9100 showed higher mechanical properties. The physical and food regulatory parameters of the bag ESB-L560 showed no significant differences before and after shockwave treatment so that product safety would not be impaired. However, a cost effective use of this bag still requires further development in the process and the bag itself as 20 % of bags are damage by the shockwave treatment.

Finally, the settings generating most energy for the shock waves (SW) were used to demonstrate the effect on tenderization of beef and pork at DTI. The effect was tested on pork silverside and loin, and beef eye of round, top side and steaks from beef full rib. The results showed that SW-technolgy improved the tenderness with approximately 1 point at a sensory scale ranging from 1 to 15. Furthermore, the effect of SW on tenderness appreciation (5.6) was much lower than the effect of brine injection (7.0) or low temperature – long-time cooking (8.3) and only comparable to the control (5.0). The study also showed that SW-treatment of pork reduced the cooking loss (2 %) in sausages added 1.8-1.9 % NaCl whereas no effect was observed in sausages added 2.2-2.4 % NaCl. It was confirmed that SW does not affect the shelf life of vacuum packed beef or pork probably because the energy formed by the SW machine did not inactive bacteria or affect the drip loss in vacuum packed beef cuts of eye of round, topside or cuvette. Overall the shockwave technology is promising but it is not economically feasible at industrial level with the conditions assayed. Further studies are needed to find out specific meat cuts and process settings to obtain significant tenderness improvements and economical profits.

Summary description of project context and objectives

Background and economic relevance

In recent years the consumer demand has shifted towards convenient, easy to prepare meat products. In Europe mainly multiple use cattle varieties (milk and meat production) are raised, providing a small amount of tender meat pieces applicable for steak production, only. To produce beef and pork meat with sufficient quality for preparation of convenience food like steaks usually a post-mortal ripening is applied. Due to a time requirement of 14 to 21 days, meat maturation causes significant storage and energy costs.

In pilot scale tests it was shown, that hydrodynamic shock wave treatment results in accelerated meat maturation and allows some improvements of meat quality and economic situation of SME meat producers. But up to now shock wave technology is not marketable. The lack of industry ready equipment, the knowledge of the process-product interactions as well as suitable packaging material has limited an industrial application of the technique so far.

In an interdisciplinary cooperation of Small and Medium sized Enterprises (SMEs) and Research and Technical Development (RTD)-performers. ShockMeat will bridge the gap from research to industrial implementation of the technique by:

- Development of an innovative industry ready shock wave equipment including meat handling,
- Identification of key processing parameters and elaboration of process-product interactions,
- Development of technology adapted packaging material,
- Deriving cost models and demonstration activities.

With an annual turnover of approx. 202 million European meat industry is the most important sector of European food industry. By enhancing meat maturation and meat tenderness product quality will be improved and processing costs reduced. ShockMeat will contribute to improve the competitiveness of SME in the area of meat processing, equipment manufacturing as well as packaging material. The consumer will benefit from meat products which are of higher quality (lower salt content, good texture, more tender, extended shelf life).

The ***overall objectives*** of ShockMeat are:

- **Development of a prototype for shock wave application**

At present, no industrial, continuously operable shock wave equipment for disintegration of biological materials is available. A continuous operability will be a key requirement for a successful implementation of the technique into industrial practice. RTD activities will be required to develop a suitable meat handling system as well as to improve treatment homogeneity by increasing the effective working area with high shock wave intensity. Within the proposed project suitable processing equipment (prototype) for an industrial application of a continuous treatment of packed meat by shock wave technology should be developed.

- **Development and characterization of packaging materials suitable for shock wave application**

In addition, shock wave resistant packaging material has to be developed to allow treatment of packaged meat. At present mechanical damages such as pinching are a major concern, but also shock wave induced alterations of the packaging material properties have not been evaluated yet. Based on preliminary tests shock wave PVC tubes have shown to be suitable, but PVC usage as food packaging material is under discussion. The selection and adaptation of suitable packaging material is a key prerequisite for a successful implementation of the technique into industrial practice. A report will describe the characteristics of shock wave resistant packaging material and the influences between this packaging material and food matrix in order to provide material that is suitable for the application of the new technology.

- **Adaption of process and meat quality analysis to verify the higher meat quality after treatment**

The technical impact on product quality will be the next step to the development of the prototype. An acceleration of meat maturation and an improvement of meat quality are expected. Reducing the maturation time will improve the competitiveness of SMEs meat processes; the improvement of meat quality will allow a standardization and reduction of variations in quality of different cuts. The evaluation of process-product interactions, the tenderness as well as shelf life will ensure that the final meat product meets the consumer expectations for a high quality and safe product.
Reports will describe the effect of the shock wave technology on the chosen food products (pork, beef) and will consider the tenderization of the meat and compare it with existing tenderizing technologies. The impact of the technology on the shelf life of the packed product will be investigated as well as the effect of shock wave on functional properties of raw material that will be later used for sausage production.

- **Evaluation of industrial application**

Different industries will benefit from the research and technological development of the proposed project: the machinery and equipment producer, producer of the packaging material, the end user of the technology, the meat processing industry, and last but not least the consumer. The SMEs involved in the project have identified the potential of the shock wave technology which is not available on the market yet and framed in cooperation with the RTD beneficiaries the ShockMeat project proposal. The development of the technique as well as a suitable packaging material will result in a broader technology and product portfolio, quality improvements and will allow strengthening competitiveness of these SMEs on the European market.
The technology will only get access to the market if the cost-benefit analysis is positive. Therefore it is necessary to scrutinize the costs (purchase cost, running cost) and estimate the added-value of the "new" meat products.

The RTD activities of the project will be realized by a joint venture of SMEs and RTD performers.

Organization of shockmeat project

Shockmeat is organised in 7 work packages (WP): one WP devoted to management (WP1), 4 WPs comprising R&D activities (WP2, development of optimized shockwave technology, WP3, shockwave-resistant packaging materials, WP4, effect of shockwave technology on meat quality, and WP5 cost evaluation), one WP dealing with demonstration of the technology (WP6) and one WP dedicated to IPR management and dissemination activities (WP7).

Project objectives per work package

WP 1. Project Management.

- To provide an efficient project administration and maintain a continuous communication between beneficiaries and to the Commission.
- To ensure a smooth project running regarding the financial and legal management.
- To achieve timely submission of progress and financial reports to the Commission.
- To ensure that the Description of Work and the Consortium Agreement is maintained and updated where necessary.

WP 2. Development of optimized shock wave technology.

- Development and realization of a continuous shock wave plant including meat handling.
- Optimization of treatment area / evaluation of spatial distribution of shock waves.
- Identification and optimization of influencing process parameters regarding the integrity of packaging material.

WP 3. Optimization of packaging materials

- Development of a model system as simulant of meat.
- Development of qualified materials that are as resistant as possible relating shock wave treatment
- Selection of the best suited materials, specified characterization: Evaluation of selected packaging materials concerning mechanical stability, permeation and migration properties.
- Identification of influences between packaging material and food during/after treatment.

WP 4. Ageing of beef and pork

- Translation of the selected packaging materials and processing parameters from model system to meat
- Treatment of different meat products (beef/pork) under variation of process parameters and comparison to traditional methods and technologies.
- Influence on shelf life and further processing abilities.

WP 5. Evaluation of cost effectiveness and overall estimation

- Estimate the cost effectiveness of shock wave application in meat industry.
- Collection of data on costs of investment and operation, determination of equipment and component lifetime.
- Comparison of technical and financial efforts to technology benefits.
- Development of cost models as a decision base for implementation of the technique.

WP 6. Demonstration

- Demonstration of shock wave technology to B2B customer group (technology: slaughterhouses; meat products: retail).

WP 7. IPR management and dissemination.

- To ensure the protection and exploitation of IP issues for the benefit of SME beneficiaries.
- Handle the knowledge management and access rights to project results.
- To inform about the project activities taking into account the confidentiality of project activities.
- To provide attractive dissemination material for participating SMEs.

Description of the main S&T results/foregrounds

The report is organised according to the four core R&D activities (shockwave technology, shockwave-resistant packaging materials, meat quality and evaluation of cost effectiveness) and the respective work packages associated:

- WP 2. Development of optimized shock wave technology.
- WP 3. Optimization of packaging materials.
- WP 4. Ageing of beef and pork.
- WP 5. Evaluation of cost effectiveness and overall estimation

WP2. Development of optimized shock wave technology.

Task 2.1: Development and building of a continuous shock wave plant

This task was based on previous DIL's experiences with shockwave technology from national funded project (AiF 15884 N) and further trials carried out at DIL during present project. Initial trials investigated the possibility of using no wire to avoid wire mediated explosion. The use of electrical discharges underwater avoid the problems associated with the use of explosives and allows a repetitive number of shocks without the need of loading/ unloading among shockwave pulses which makes the application more feasible in terms of automation, reduces the processing time of the treatment and allows an easier modulation of shockwave intensity by delivery of different electrical intensities and/or number of pulses per treatment (Figure 2.1).

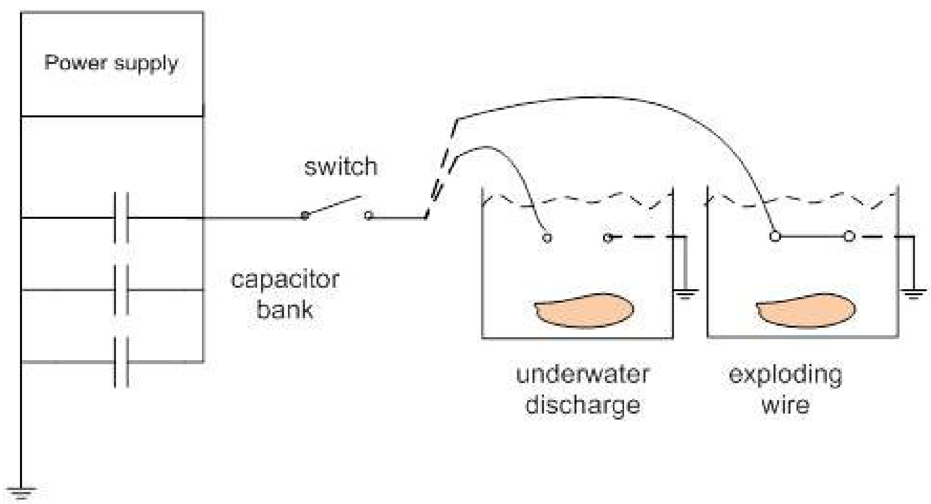

Figure 2.1. Electrical discharge mediated by wire or not mediated by wire.

Some additional tests with meat were carried out to ensure practicability of the prototype before final construction (Table 2.1). It was shown that with this preliminary design was possible to tenderize meat especially steaks although bigger pieces will require additional energy as expected (Table 2.1, silverside).

Table 2.1. Tenderness improvement by hydrodynamic shockwave treatment with the new developed prototype (mean ± standard deviation).

Meat				Treatment[#]			
Specie	Primal cut	Format		no. pulses	Control	Shockwave	WBSF[##] Improvement
					(kg)	(kg)	(%)
Pork[###]	Topside	Entire piece[#####]		2	4.3 ± 0.5^{a}	4.3 ± 0.6^{a}	-0.8
Beef[####]	Silverside	Entire piece		2	7.0 ± 1.3^{a}	6.7 ± 1.6^{a}	4.8
	Silverside	Entire piece		5	8.4 ± 2.3^{a}	6.3 ± 1.7^{b}	24.8
	Loin	Steaks[######]		1	4.8 ± 0.8^{a}	3.9 ± 1.1^{b}	18.1

[#]: Different superscript letter within the same row means a significant difference at p-value < 0.05.
[##]: The texture was measured by standardized Warner-Bratzler Shear Force (WBSF) procedure after 7 days of storage, simulating the commercial life of the meat from processor to supermarket and consumer.
[###]: Conventional commercial pork meat.
[####]: Holstein young bulls.
[#####]: Entire pieces were longitudinally split in halves, where half served as control (C) and the other half was treated by shockwave (SW).
[######]: Steaks of 26 mm were taken for C and SW.

Based on experience and trials, the following premises were considered of special relevance for the development of the new shockwave plant:

- An electrohydraulic discharge with an exploding wire destroys the packaging and contaminates the meat with metal pieces.
- A higher voltage produces a higher intensity shockwave.
- A higher pressure and a faster pressurisation increase a better tenderisation.
- The construction has to be very strong to resist the shockwaves.

It was decided to use electrohydraulic produced shockwaves without using a wire. To reach the same shockwave intensity different considerations have to be taking into account in the mechanical and electrical design in order to optimise the focus and intensity in a reasonable and feasible manner. In the Figure 2.2 it can be observed a rough preliminary approach to redefine the old treatment area into the new treatment area. Further test proved that this approach was far more efficient.

Different variables were considered in the design and the trials:

- Use of no wire
- Horizontal disposition of electrodes
- Parabola reflector

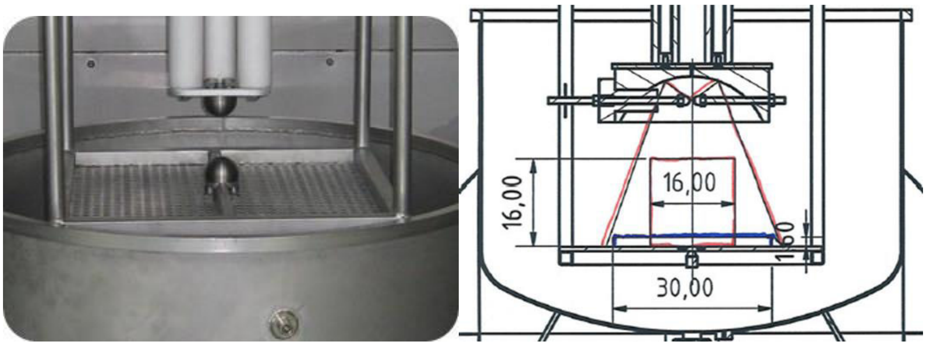

Figure 2.2. Design consideration on the treatment area.

In the Figure 2.3, it can be observed the old prototype designed and constructed by DIL in a previous project and in the figure 2.4 the novel prototype.

Figure 2.3. Shockwave prototype intended for meat tenderization developed within a German-funded research project, AiF-15884 N (2008-2011).

Following the premises established, a prototype plan was outline (deliverable 2.1) and further constructed (Figure 2.4).

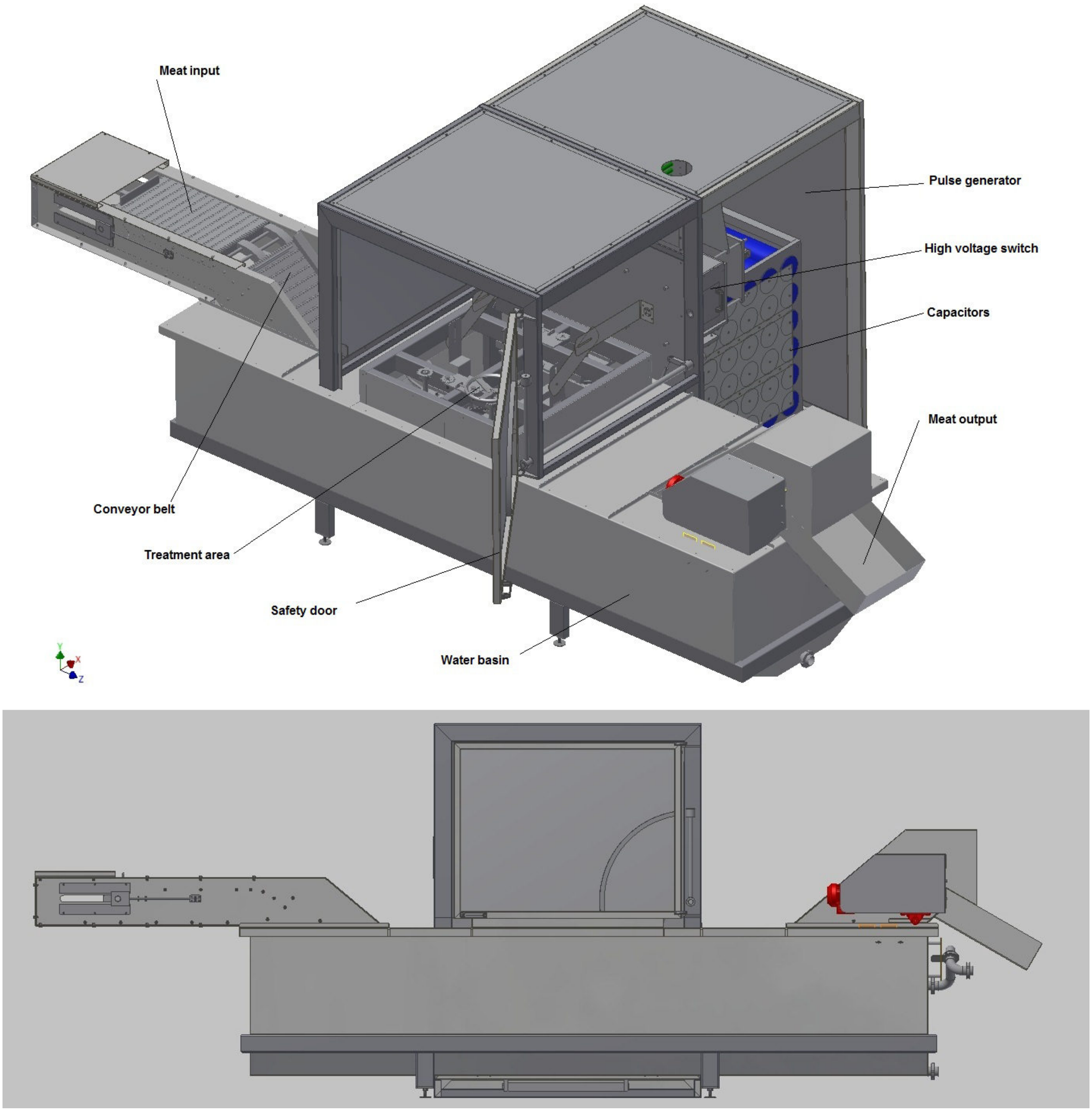

Figure 2.4. Main parts of shockwave prototype intended for meat tenderization developed within the European-funded research project, ShockMeat (2012-2014).

The operational principle of the new shockwave prototype for meat tenderization is shown in the Figure 2.4 by its different parts. The unit consists of a high voltage power supply, a capacitor bank as well as a high voltage/ current switch to discharge the stored electric energy across the electrodes. By variations of charging voltage and capacity, the energy per pulse can be varied from 36 to 14400 J per pulse. The treatment intensity can be further adjusted by the number of pulses applied. A conveyor belt has been adapted to allow a continuous treatment. Safety issues as well as robustness of the prototype have been given high priority during the mechanical development. The treatment area has been re-designed taking into account the sizes of common meat cuts from beef and pork and to effectively deliver the shockwave to the meat. The prototype has been tested in the first phase of the project showing promising results on the tenderness (Table 2.1) and was further tested in a second phase by the Danish Meat Research Institute (DTI).

Safety issues have been given priority during the development of the prototype. Different considerations were taken into account in the design as well as to establish a safety procedure.

Safety Arrangements in the construction

- Impossible accessibility to the treatment area and electrical connections.
- Safety mechanism. Safety door ensures that if someone opens the door the machine stops immediately by a physical triggered mechanism and the capacitors discharge with a mechanic system.
- Closed pulse generator.
- The treatment area is out of a strong corpus which resists the shockwave. If something eventually will break, the pieces will be collected in the housing of the water tank. The extra housing over the water tank could collect pieces too. But there are only a few pieces which will be next to the shockwaves.
- Shockwave exists only out of pressed water. The best absorber is air because air is compressible.
- No possibility to clamp your fingers at the moving conveyor belt. There are safety metal sheets to prevent from moving parts. In addition the conveyor belt is moving very slowly.
- Noise. The machine will be loud. A noise exposure of 90-105db could be possible (similar to a little pneumatic hammer). The noise exposure depends on the shockwave intensity, ear protection are required during operation.
- Recommendations to avoid noise exposure. If the machine is too loud for industrial standard, we need an extra noise protecting housing or place in a different cabin.

Safety procedure

A procedure is in-place to guarantee safety operation.

Technical service and re-design during operation

The operation of the prototype has been very challenging and has required an extra effort in terms of technical support for regular operation and trial conduction at DTI. In addition, this has led to additional re-designs and improvements of key components of the prototype to make them safer and more resistant.

Task 2.2. Optimization of treatment area/evaluation of spatial distribution of shock waves

To allow maximum treatment efficiency and capacity the detection and optimization of the working area is of high importance. Making use of different electrode distance and number, length of the exploding wire as well as area of the actuator the area of shock wave generation can be varied. By reflection and focussing the working area size can be additionally changed. In this context, a pressure sensible film has been used to detect the spatial distribution of the shock wave intensity and elaborate design and scale-up guidelines to obtain maximum treatment homogeneity and needed intensity for meat tenderization.

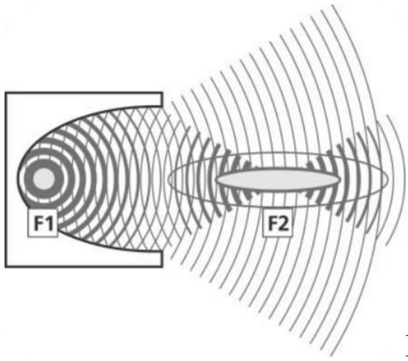

Figure 2.5. Hydrodynamic pressure processing or shockwave.

The application of a high energy by capacitor discharge underwater between two electrodes leads to the formation of a plasma channel wherein the medium is ionized. The electric breakdown of liquids is initiated by the application of high electric field on the electrode followed by rapid propagation and branching of plasma channels. Different conditions on the machine were investigated to find out optimal conditions producing uniform and intense shockwaves.

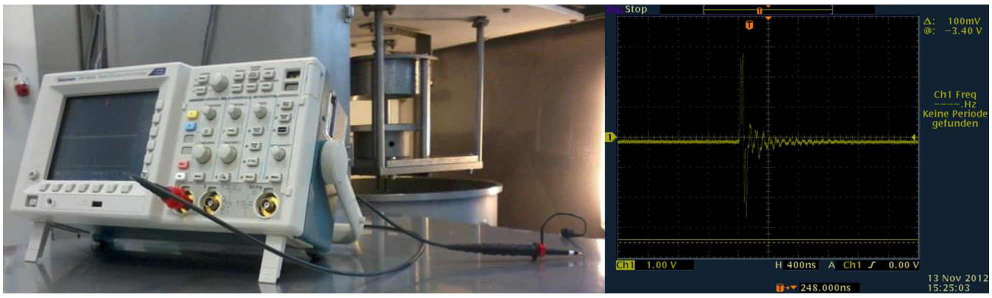

Figure 2.6. Electrical definition of the electrical discharge.

The quantification and comparison of the pressure distribution between old treatment area and new treatment area was carried out as a foundation for an effective hydrodynamic pressure processing or shockwave intended for meat tenderization (deliverable 2.2).

It must be noted that studies dealing with the quantification of the spatial pressure distribution in shockwave treatment are very scarce especially in applications addressing food systems. Several studies exist in the medical field where the technology is more developed, however, the level of energy required as well as the application area are considerable higher in food applications. The methodology to measure pressure of shockwave was developed during the project running. The meat substitute or gelatine matrix developed by OFI was used to evaluate pressure gradients and simulate as well test with packaging materials.

Within a nationally funded project (AiF 15884 N, 2008-2011) DIL acquired its first experiences with shockwave technologies. In this last project a batch wise working prototype was built which was probed to be effective for meat tenderization. Taking this as a fundamental point, the characterization of the pressure distribution of this shockwave and its reproduction must be a way of creating the pressure conditions for an effective meat tenderization. However, the previous prototype was operated by using a wire mediated discharge. This was avoided to prevent that spilled particles from the explosion damage the packaging. This is connected to task 2.3, “Identification and optimization of influencing process parameters regarding the integrity of packaging”, where also the distribution of the pressure over the whole treatment area avoiding hotspot must be in this case beneficial. Some of the pertinent results are shown in Table 3.1.

The new treatment area was optimised to reproduce high intensity shockwave required for meat tenderization purposes by reducing size of the treatment area to a minimum, focus the shockwave with a parabola and investigating the variables of the electrical discharge like voltage. The number of pulses permits a further adjustment of the energy and thus pressure delivered to the meat. The new treatment area delivers a homogenous pressure distribution over the whole treatment area which is beneficial also for the resistance of the packaging material.

WP 3. Optimization of packaging materials

Task 3.1. Development of a model system as simulant of meat

After a detailed literature research and countless preliminary tests, four meat substitutes were prepared and tested at the DIL with a texture analyser in terms of their texture similarity with cooked and raw beef.

Following gel formulations were used for the above mentioned investigations:

- Gelatine 40%, Gelatine 38,4% with 1% wheat fibers, Gelatine 36,8% with 2% wheat fibers
- Cooked meat and raw meat as a reference for comparison

Due to the simplicity of preparation and the good comparability to the experiments performed for all the following tests the gelatine 40% was agreed as a model substance. The manufacturing process has been optimized subsequently, so that the production of larger amounts of samples could be done. Even at a maximum voltage of 40 kV and multiple impacts in succession the meat substitute resists the shock wave treatment as well as raw meat.

Task 3.2 and 3.3. Development of qualified materials that are resistant as possible relating shockwave treatment and selection of the best suited material, specified characterization

1. Preliminary selection for orientation

Table 3.1 shows the results of the screening of different packaging materials from the European market that were tested for their applicability during shockwave treatment was screened for their mechanical properties. The bags, made from different types of plastic composite films were tested in December 2012 at the DIL. Each bag had dimensions of 200x300mm and was treated two times at 36kV. For better practical relevance each bag was filled with meat simulant (gelatine). Films that resisted the shock wave treatment at 36kV for two times were then tested at 40kV (only one shot). For the second tests there were always a new bag filled with meat simulant.

Table 3.1. Results of the shockwave treatment with gel filled bags in December 2012 at DIL.

testing method	standard	unit	plastic film type [mean values]							
			scheyer bags				supplier 1 bags			
			PA/PE 90µm	PA/PE 150µm	PA/PE 180µm	PA/TPU 120µm	laminate 90µm	laminate 40µm	laminate 170µm	laminate 50µm
Puncture resistance – Fmax inside	OFI-method V45	N	10	15	28	35	47	22	72	22
Puncture resistance – Wmax inside	OFI-method V45	N	35	51	104	270	245	76	320	103
Puncture resistance – Fmax outside	OFI-method V45	Nmm	13	16	36	34	50	19	66	22
Puncture resistance – Wmax outside	OFI-method V45	Nmm	56	60	172	253	272	58	285	104
Puncture resistance – Fmax inside	EN ISO 6603-2	N	---[1)]	98	254	218	596	219	1045	238
Puncture resistance – Fmax outside	EN ISO 6603-2	N	---[1)]	97	263	220	544	196	914	---
Puncture resistance – Wm/Wp inside	EN ISO 6603-2	J (N/m)	---[1)]	0,6/1	1/3	5/6	7/7	2/2	8/8	2/3
Puncture resistance – Wm/Wp outside	EN ISO 6603-2	J (N/m)	---[1)]	0,5/1	2/3	6/6	6/7	1/2	6/6	---
Tensile test (longitudinal/transverse) - σM	ISO 527-3	MPa	36/24	29/22	42/40	54/53	77/79	68/62	77/67	78/68
Tensile test (longitudinal/transverse) - εB	ISO 527-3	%	235/284	283/313	288/316	365/386	160/175	88/76	110/100	120/172
testing method	standard	unit	plastic film type [mean values]							
			supplier 2 films			supplier 3 films		supplier 4 films		
			PA/PE 80µm	PA/PE 150µm	PA/PE 240µm	PA/PE 170µm	PA/PE 90µm	PA/PE 130µm	PA/PE 135µm	PA/PE 140µm
Puncture resistance – Fmax inside	OFI-method V45	N	8	21	31	19	10	19	21	23
Puncture resistance – Wmax inside	OFI-method V45	N	30	100	122	70	33	75	84	109
Puncture resistance – Fmax outside	OFI-method V45	Nmm	11	24	28	22	15	19	23	17
Puncture resistance – Wmax outside	OFI-method V45	Nmm	47	121	99	89	71	79	99	53
Puncture resistance – Fmax inside	EN ISO 6603-2	N	96	357	337	231	150	279	306	221
Puncture resistance – Fmax outside	EN ISO 6603-2	N	93	200	292	211	111	303	306	232
Puncture resistance – Wm/Wp inside	EN ISO 6603-2	J (N/m)	1/1	12/13	3/4	2/3	2/3	10/---[2)]	8/8	3/4
Puncture resistance – Wm/Wp outside	EN ISO 6603-2	J (N/m)	1/1	3/3	2/4	2/3	1/1	10/---[2)]	8/8	3/4
Tensile test (longitudinal/transverse) - σM	ISO 527-3	MPa	25/21	36/35	37/33	35/26	47/43	45/38	47/43	47/40
Tensile test (longitudinal/transverse) - εB	ISO 527-3	%	335/264	328/318	330/342	299/312	407/382	360/542	369/380	413/397

red=	damaged after shockwave treatment
green=	no damage after shockwave treatment, min. 40kV

1) too less samples available

2) destruction way was too short to fully destroy the sample (sample material was too flexible)

As it can be seen from Table 3.1 the following bags resisted the shockwave treatment filled with gelatine unscathed (green ones):

– 170µm shrink bag from supplier 1
– 150 and 240µm PA/PE- from supplier 2
– 120µm PA/TPU/PA-bag produced by SVE
– 130µm PA/PE-composite film from supplier 4

These films and a new film developed by Scheyer (120µm PA/ PE laminated film bag) as well as the commercial films of both Danish meat producers (a shrink bag with 50µm from supplier 1 and a PA/PE composite film) were filled with meat and were again treated with shock waves, to verify the earlier results. Again the first tests were made with meat simulant, it was determined very soon that bags filled with meat are exposed to higher stresses than bags filled with gelatine. This could be a result of the higher damping behaviour of meat compared to gelatine. Meat is also less homogenous and there are more air inclusions than in the meat simulant. This results in higher loads of energy to the packaging materials used. Based on these findings it has been decided to carry out further investigations with bags filled with meat. The pork meat was treated three times and the beef five times in succession, both at 36kV. The integrity of the bags was checked visually directly after the treatment and 2-4 hours later to assess the suitability of the different materials. Every trial was conducted in triplicate determination.

It was pointed out during the tests that the conditions changed during the operation and materials already known as resistant became damaged. This is partly due to abrasion of the parabolic (currently aluminium), which can lead to bag damage during the shock wave process. The experiments with bags filled with meat, very close to the sealing (short distance to the seals) surprisingly showed a very low susceptibility to cracking of the seals. Usually only the self-made sealing was affected. These tests showed that only both commercial shrink bags (170µm and 50µm) withstand the shockwave process. Especially for the shrink bags no significant leaks were detected by damaged sealing. Only those materials were used for the assessments that were generally classified as suitable for the shock wave process.

Some of the damaged packaging materials tested at DIL were tested at the OFI with a colour test (Rhodamin B test – leakage test for sealings). The positions of leaks were located and the direction of the forces acting on the surface was examined by a photomicroscope. The result was that all damages were caused by a force from the outside to inwards.

The mechanical characterization of both commercial shrink bags (170µm and 50µm) provided an informative basis regarding the high commercials needed from the materials to be used. Both of them were 100% or at least partially resistant to the shock wave process. The partially large number of materials and layers, which were used for the production of the bags, are not realizable to produce in an industrial way during the project duration. Because of that, alternative solutions had to be found and as a consequence the following composites were identified by executing a mechanical characterization:

- LDPE/LLDPE blend (100-200µm)
- PET-G (300µm)
- LDPE/LLDPE blend/SEBS/LDPE/LLDPE blend (150-200µm) – it was not possible to obtain samples of SEBS-films on the European market; that's why this film construction was not further investigated
- EVOH composites with high stiffness (70-105µm) from SVE (new development)
- TPU-composites (50-250µm)

LDPE/LLDPE blends, PET-G, EVOH-composites with high stiffness and TPU-composites were ordered as samples and in consequence mechanically characterized. These investigations showed that the developed SVE ESB L-560 (105µm) and the 170µm commercial shrink bag from supplier 1 used as a reference material show almost similar high values for the different mechanical parameters tested (for more details see table 2 in deliverable 3.2). The values of the LLDPE/LDPE blends, of the Surlyn film and all of the TPU-films were far behind the expectations. Also the alternative PE-EVOH composite from SVE with a thickness 70µm could not reach the high mechanical firmness of the ESB-L560 bag. The biaxial stretching should be responsible for the huge strength of the commercial and the EVOH-bags from SVE that was measured. However, biaxial oriented LDPE/LLDPE or TPU films are not available on the European market. For that reason it was decided to stop considerations about these materials. Suggestions were made about the possibility to use the LDPE/LLDPE films as a sealing layer for the compounds to be developed. Also the PET-G film showed, against all expectations, consistently very low values for the mechanically characteristics tested. It was concluded that this film is not applicable for the shock wave process. Due to the outstanding mechanical strength of the SVE PE-EVOH laminate ESB-L560 105µm a vacuum bag in the requested size (500x280mm) from this material was produced by SVE for the test at DTI where the bags were tested in the shock wave process. Basically the combination of penetration work and penetration power of both methods (static and dynamic loads) is a good indicator for high puncture resistance and thus the resistance to the shock wave process. The tensile indicators (breaking stress and elongation) give additional information regarding to the material strength, especially the maximum strength and elongation. Therefore these indicators complement the obtained penetration resistance.

Task 3.4. Identification of influences between packaging material and food during/after treatment

To identificate possible influences of the shockwave process of the package material on food mechanical, physical and chemical analyzes were done for the commercial bag with 170µm and the Scheyer ESB-L560 with 105µm thickness before and after the shockwave treatment.

Table 3.2. Mechanical and physical properties of developed composites and commercial bags before and after shockwave treatment.

testing method	standard	unit	commercial bag, 170µm		Scheyer ESB-L560, 105µm	
			non treated	sw-treated	non treated	sw-treated
oxygen permeability (23°C/50% rH)	ASTM F 1927	cm^3/m^2.d.bar	12	15	3	4
water vapor permeability (23°C/85% rH)	ASTM F 1249	g/m^2.d	0,4	0,4	3	2
Puncture resistance – Fmax inside	***ofi***-method V45	N	72	68	80	74
Puncture resistance – Wmax inside	***ofi***-method V45	Nmm	321	338	327	267
Puncture resistance – Fmax outside	***ofi***-method V45	N	66	69	66	57
Puncture resistance – Wmax outside	***ofi***-method V45	Nmm	285	322	221	178
Puncture resistance – Fmax inside	EN ISO 6603-2	N	1060	1127	n.t. t.l.s.	736
Puncture resistance – Fmax outside	EN ISO 6603-2	N	937	982	698	627
Puncture resistance – Wm/Wp inside	EN ISO 6603-2	J (N/m)	13/14	14/15	n.t. t.l.s.	7/8
Puncture resistance – Wm/Wp outside	EN ISO 6603-2	J (N/m)	9/10	11/12	6/6	5/6
Tensile test (longitudinal/transverse) - σM	ISO 527-3	MPa	67/68	57/55	114/112	107/110
Tensile test (longitudinal/transverse) - εB	ISO 527-3	%	110/100	128/122	96/113	99/111
Seal bond strength (average)	DIN 55529	N/15mm	26	24	63 (ISO 527-3)[1]	57 (ISO 527-3)[1]
Compound adhesion	DIN 53357	N/15mm	not feasable	not feasable	not feasable	not feasable
Overall migration testing with 3 % acetic acid (10d/20°C)	ÖN EN 1186	mg/dm2	<1	1,1	2	2
Overall migration testing with 95 % ethanol (10d/20°C)	ÖN EN 1186	mg/dm2	<1	<1	<1	<1
Overall migration testing with iso octane (10d/20°C)	ÖN EN 1187	mg/dm2	1,2	1,2	1,8	1,5
Overall migration testing with destilled water (10d/20°C)	ÖN EN 1187	mg/dm2	<1	1,4	<1	1
Specific Migration testing for Irganox 1076 with 95% Ethanol (10d/60°C)	VO (EU) 10/2011	mg/kg	0,03	0,03	0,2	0,2
Specific Migration testing for acetic acid vinylester with 95% Ethanol (10d/60°C)	VO (EU) 10/2011	mg/kg	0,03	0,03	0,2	0,2

n.t. t.l.s.…not tested, too less samples
1) because of the high seal bond strenght of the laminate ISO 527-3 was used instead of DIN 55529 (not measureable)

As it can be seen in Table 3.2 there were no significant differences regarding permeability behaviour of the examined packaging material composites (water vapour and oxygen permeability) before and after shockwave treatment that could decrease product safety. In addition, shockwave treatment showed no significant influence on the tested packaging material relating to migration behaviour, what confirms food regulatory conformity. A slight decline was observed concerning mechanical characteristics, which is considered to be negligible because after shockwave treatment the mechanical requirements for packaging materials are marginal in comparison. It is shown that the integrity of the composite films is not or only slightly influenced by shock wave treatment.

WP 4. Ageing of beef and pork

Task 4.1. Translation of the selected packaging materials and process parameters from model system to meat

After the semi-industrial batch prototype was reconstructed and adapted by DIL, and transferred to DTI, qualifying examinations of the commercial bags and the ESB-L560 105µm bags from SVE were started, with the final shockwave prototype. The essential differences to the first prototype were on the one hand the automatically transport of the packed meat, and on the other hand the continuous generation of shock waves during the transport of the meat. In comparison the shockwave tested in a preliminary design of the treatment area with the new shockwave prototype at DIL were only statically (35 by 40kV) without any movement of the treated product. It was pointed out very quickly, after a few treatments, that the commercial bag with 50µm from supplier 1 does not withstand the high mechanical load of the process and the majority of the bags were damaged. Because of these results the packaging material was not further tested. It seems that because of the continuous shockwave treatment, caused by the further developed machine, there are far higher loads caused on the packaging material, than were determined with the first prototype at DIL. In contrast the second commercial bag with 170µm from supplier 1, as well as the ESB-L560 105µm from SVE, showed a better resistance against the shockwave treatment. Nevertheless, about 20% of the two bag materials were damaged. The damages observed were small pinholes (primarily started from the inside of the bags) up to big holes caused by burning and large cracks that damaged the whole bag. Furthermore the commercial bags showed increased damages of the sealing. The inner sealing bag in this composite is 60µm thick. The high strength of this bag is because of the high stiffness of the outer film, which is only adhered on the inner bag. Because of this only the bottom sealing bond of the inner 60µm bag is mechanically stressed, and therefore only resistant in a limited way. In comparison the SVE-bag with a thickness of only 105µm is sealed over the whole film thickness which results in a very high sealing strength. This was observed during the tests, because none of the sealing bonds broke. Such damages occur if, the meat has not enough space to expand inside the bag, which leads to an enormous mechanical pressure on the sealing bonds.

Figure 4.1. Example of damage of the commercial shrink bag 170µm (left) and sample for broken sealings (broken inner bag material very near to the sealing itself) on the bottom of the bag of commercial shrink bag 170µm (right).

Subsequently the damaged bags of both material types were analysed at the OFI visually and microscopically to examine probable basic reasons for the damages. Both bag types (ESB-L560 and commercial bag) showed partially massive damages caused by high energy impact (probably in consequence of a flash-arc) which leads to burning that started at the inside of the bag. Furthermore big scratches were also detected that also could be caused by very high energy exposure to the bags. There is a suspicion that the process is not running continuously enough so that sometimes energy peaks occur or the position of the bags shifted during transport in the machine and this leads to partially very high forces that as a consequence affect the bags. To avoid this by optimising the packaging material is not easy and not economical. So an optimization of the shockwave process itself would be more efficient. To try to prevent these problems, encountered by the shockwave treatment, two new composite films were developed by SVE and OFI.

Because the shockwave machine was brought back to Germany at the end of March 2014, further tests only with one of the new composite films were carried out at DIL. The bags, produced by SVE from the film 1, with the dimensions 500x320 mm, were filled with meat at DIL, and afterward evacuated and tested for shockwave treatment. The tests showed that the SVE V9100 with 141µm thickness showed nearly the same performance as the SVE ESB-L560. Simultaneously, again a mechanical characterization of the two composite films was done, to objectively assess their suitability for the shockwave process, and to compare their mechanical characteristics to the commercial bag, that is probably suited for the process. The results of the bag, SVE V9100, with 141µm thickness, showed in some parameters a higher and in some parameters nearly the same mechanical and physical characteristic as for the commercial bag. So this bag type should have the best performance for the shockwave treatment.

In addition, a bottom film was produced for thermoforming in the last two months of the project. It was planned also to produce a TPU-composite for thermoforming, but it was not possible to reach a sufficient high composite liability during lamination at SVE installations, so this idea was abandoned. For the deep drawing of the thermoforming film a simple deep-draw mould was produced and the film was deep drawn with the dimensions 255x155x45. The thermoforming of the relatively thick and therefore stiff film proved to be very problematic. Altogether the film was very difficult to thermoform, but as this was possible, cracks arose at the edges or the bottom became very thin. In both cases, these thin moulds would not withstand the shockwave process. In addition delamination occurred in the bottom. Maybe the film could be thermoformed at special machine configuration but this is not a standard in the food packaging sector. So, further development of this composite film was stopped.

Figure 4.2: Results of the deep drawing process of the potential thermoforming TPU based film.

Task 4.2. Treatment of different meat products (beef/pork) under variation of processing parameters

Effect of shock wave on tenderization of pork and beef

The effect of shock waves was evaluated in relation to improved eating quality for different types of cuts for both beef and pork. The evaluation was based on sensory analysis, Warner Bratzler shear force texture analysis and cooking loss and was performed in relation to each of the following experiments:

- Optimization of equipment parameters and packaging
- Effect of shock waves on two different muscle types from pork (pork loin and the outer ham muscle)
- Effect of shock waves on beef eye of round and impact on 4 different ageing times.
- Effect of shock waves on beef silver side and impact on 4 different ageing times.
- Effect of shock wave treatment on retail cuts from beef – steak from filet.
- The effect of repeated shock wave treatment of beef eye of round
- Comparison of shock wave technology with other tenderizing technologies i.e. Low Temperature Long Time treatment (LTLT) and brine injection.

<u>Optimization of equipment parameters and packaging</u>

The packaging material shown to be among the best in WP3 was OSB95TBG and OSB3050. In the initial screening, it was shown that OSB95TBG was far more resistant to the shock wave treatment than OSB3050. Furthermore a new packaging film from OFI and Scheyer was also included in subsequent tests. It was shown that excess packaging material compared to the meat in the packages resulted in floating packages that could not enter the treatment area of the machine.

The various settings of the SW-machine were tested to find the optimum settings for the meat trials. The parameters varied were: Voltage (20-40 kV); Parabola distance to belt (80-150 mm); Electrode distance (4-20 mm); Step (1-10) and Belt speed (50-100%). The most important parameters were: Voltage, electrode distance and parabola distance, in order to achieve energy that was high enough in relation to the shock wave energy. The optimization ended with the maximum settings the machine could run at without breaking down too often. The isolators at the electrodes was the ones breaking down most often and no really good solution was found, as the isolators kept breaking down during the entire project. During the trials, pressure sensitive paper was run through the machine before the first package of meat and after the last package of meat. These papers showed different intensity of colouring, indicating that the shock waves generated during running did not have a uniform intensity during the tests or that the pressure sensitive paper did not act in a uniform way.

Effect of shock waves on two different muscle types from pork (pork loin and the outer ham muscle)

The aim of this study was to investigate the effect of shock wave technology on the pork loin with a fat layer and the outer ham muscle. The effect of shock wave technology was evaluated in relation to colour and eating quality with focus on texture properties such as tenderness.

The effect of shock wave treatment on three ***colour*** parameters (a, b and L-values) was analysed in SAS with a T-test in individual models, with treatment as fixed effect . There was a significant effect ($P<0.05$) of the a-value for the outer ham muscle as samples subjected to shock wave treatment were more intense in the red-green hue compared to the control samples. There was no effect of shock waves on the colour parameters for samples from pork loin.

Pork loin was characterized in a ***sensory profile*** by 10 attributes focussing on the texture properties. There was a significant effect of shock wave treatment on hardness and crispness ($P<0.05$). Mean scores for the sensory descriptors, grouped by treatment, are reported in Table 4.1.

The sensory profile analysis for the outer ham muscle was performed with 9 attributes and showed a significant effect of shock wave treatment on hardness and chewing time ($P<0.05$) (results not shown).

Table 4.1. Mean sensory ratings grouped on treatment for pork loin.

		SW	Control	P-value	Bonferroni LSD
Taste	Sour	4.8	5.1	NS	0.29
Flavour	Piggy	1.7	1.8	NS	0.39
	Meaty	6.2	62	NS	0.31
Texture	Hardness	3.7	4.8	P<0.05	0.91
	Structure	5.1	5.5	NS	0.75
	Crispness	3.8	4.6	P<0.05	0.63
	Juiciness	4.2	4.5	NS	0.50
	Crumbliness	9.0	8.1	NS(P=0.06)	0.82
	Tenderness	10.2	9.7	NS	0.64
	Chewing time	5.6	6.3	NS	0.81

Warner Bratzler shear force texture analysis was conducted on both pork loin and the outer ham muscle. Mean peak shear force grouped on treatment is presented in the table 4.2 showing that SW-treatment reduced peak shear force ($P<0.05$) for pork loin and the outer ham muscle ($P<0.01$) .

Table 4.2. Mean Warner Bratzler peak shear force for pork loin and the outer ham muscle, grouped on treatment.

	SW (newton±STD)	Control (newton±STD)	P-value	STD
Loin	39.3 ± 5	43.5 ± 5	P<0.05	0.2
Outer ham muscle	50.8 ± 9	70.7 ± 11	P<0.01	0.7

There was no effect of shock wave treatment on ***cooking loss*** (Pork loin (P<0.5), outer ham muscle (P<0.4)).

<u>Effect of shock waves on beef eye of round and impact on 4 different ageing times</u>

The effect of shock wave treatment was investigated in relation to improved eating quality for beef eye of round and the effect on ageing time (3, 7, 14 and 21 days at 0 – 2 °C). The effect was evaluated in a sensory profile analysis and by instrumental texture analysis. There was a significant effect (P<0.001) of treatment on the sensory properties attributes well done appearance, sour taste, bite resistance, juiciness, tenderness and chewing time. Mean scores grouped on treatment are reported in Table 4.3. Samples treated with shock waves were described as more intense in juiciness compared to the control samples and, high scores for well-done appearance were more pronounced for the control samples compared to the samples treated with shock waves.

Table 4.3. Mean sensory scores for eye of round

	Day 3		Day 7		Day 14		Day 21			
Attributes	SW	Control	SW	Control	SW	Control	SW	Control	P -values	Bonferroni LSD
Appearance										
Well done	5.7^{bc}	5.9^{bc}	5.2^{c}	7.2^{a}	5.3^{c}	5.0^{bc}	5.5^{bc}	6.8^{ab}	P<0.001	1
Taste										
Sour	4.8^{a}	5.0^{a}	5.0^{a}	4.8^{a}	4.4^{b}	4.5^{a}	4.4^{b}	4.6^{a}	P<0.01	1
Sweet	3.5	3.8	3.6	3.9	4.1	3.8	4.1	4.1	NS	1
Bitter	3.3	3.6	3.6	3.7	3.1	3.3	3.2	3.6	NS	1
Flavour										
Meat	6.1	6.2	6.2	6.5	6.3	6.2	6.1	6.4	NS	1
Metallic	4.6	4.6	4.3	4.4	4.0	4.1	4.5	4.7	NS	1
Texture										
Bite resistance	6.8^{ab}	7.0^{a}	6.3^{ab}	6.7^{ab}	5.9^{b}	6.5^{ab}	6.5^{ab}	6.8^{ab}	P<0.01	1
Juiciness	6.3^{ab}	5.7^{abc}	6.5^{a}	5.4^{c}	6.1^{abc}	5.9^{abc}	5.8^{abc}	5.6^{bc}	P<0.001	1
Tenderness	5.6	5.4	5.9	5.6	6.3	5.3	5.5	5.4	NS	1
Fibrous	5.2	5.6	5.0	5.0	5.0	5.3	5.0	5.2	NS	1
Crumbly	3.9	4.0	4.6	4.8	4.5	4.0	4.4	4.6	NS	1
Chewing time	7.7^{a}	7.9^{a}	7.3^{ab}	7.6^{a}	6.8^{b}	7.6^{ab}	7.4^{ab}	7.5^{ab}	P<0.01	1

Effect of shock waves on beef silver topside and impact on 4 different ageing times.

The aim of this study was to investigate the effect of shock wave technology on beef silver topside aged for 3, 7, 14 and 21 days, stored at 0 – 2 °C. The effect of shock wave technology was evaluated in relation to Warner Bratzler peak shear force measurements. Mean peak shear force for each treatment is presented in Table 4.4. The results shows no effect of shock wave treatment on peak shear force for any of the four ageing time (P=0.32). There was no difference in shear force between ageing times (P=0.7).

Table 4.4. Mean peak shear force grouped on treatment and ageing time.

	Mean peak shear force (newton ± Std Dev.)	
Ageing time	Control	SW
3	71.5 ± 14.5	70.1 ± 15.0
7	66.4 ± 14.8	63.0 ± 13.0
14	65.85 ± 11.3	63.6 ± 12.0
21	62.6 ± 9.1	58.9 ± 14.5

Effect of shock wave treatment on retail cuts from beef – steak from filet.

The aim of this study was to investigate the effect of shock waves on steaks. The effect was evaluated in relation to eating quality and improved tenderness. The overall variation between the samples could be ascribed to sensory differences mainly characterized by the texture descriptors bite resistance, tenderness, crumbliness and chewing time. Only texture attributes seperated the two treatments significantly (P<0.001). As seen in Table 4.5, the taste attributes did not contribute very well to the differentiation between the treatments.

Table 4.5. Mean sensory ratings for steaks grouped on treatment.

	Attributes	Control	Shock wave	P-value	Bonferroni LSD
	Well-done	6.1	6.1	NS	5
Taste	Sour	4.8	4.6	NS	2
Flavour	Meaty	6.8	7.3	NS	3
	Metallic	3.4	2.9	NS	2
Texture	Tenderness	4.5	5.3	P<0.001	4
	Chewing time	11.0	10.2	P<0.001	4
	Crumbly	2.1	2.5	P<0.001	3
	Bite resistance	9.5	8.9	P<0.001	3
	Juiciness	7.9	7.6	NS	4

The effect of repeated shock wave treatment of beef eye of round

The aim of this study was to investigate the effect of repeated shock wave treatment compared to a single treatment on the same piece of meat. It was planned to treat the meat 0, 4 and 8. Due to break down of the machine, however, only 0, 1 and 3 treatments were achieved. When several treatments were applied to the meat, the packages were turned upside down to apply the treatment from both sides in case the shock wave intensity differed on the top and on the bottom side of the packages running through the machine. The effect was evaluated based on peak shear force obtained by Warner Bratzler shear force measurements. Mean peak shear force (table 4.6) showed no difference in peak shear force between treatments (P=0.893).

Table 4.6. Mean ± standard deviation of cooking loss (%) and mean peak shear force (N) values for beef eye of round grouped on treatment.

Number of shock wave treatments	Cooking loss %	Force 1 N
0	10.2 ± 2.8	53.0 ± 8.5
1	14.1 ± 2.7	53.3 ± 11.2
3	14.2 ± 2.8	55.2 ± 14.6

Comparison of shock wave technology with other tenderizing technologies i.e. Low Temperature Long Time treatment (LTLT) and brine injection

The aim of this study was to compare shock wave technology with other tenderizing technologies such as Low Temperature Long Time Treatment (LTLT) and brine injection. The effect was evaluated in relation to eating quality and improved tenderness. The overall variation between the four treatments could be ascribed to differences in texture properties that clearly differentiated LTLT from the remaining technologies (P<0.001).

Table 4.7. Mean sensory scores grouped on treatment.

		LTLT	Brine Inject.	SW	Control	P-values	Bonferroni LSD
Appearance	Well done	10.3	5.2	4.2	5.1	P<0.001	1.36
Taste	Salt	2.4	7.3	2.1	2.1	P<0.001	2.15
	Sour	4.0	4.3	4.4	4.8	NS	1.14
	Sweet	3.5	3.7	3.2	3.1	NS	1.16
	Bitter	3.3	2.8	3.2	3.5	NS	1.00
Flavour	Meaty	8.7	5.8	5.4	5.4	P<0.001	2.04
	Metallic	3.0	4.1	4.0	4.3	P<0.01	0.97
Texture	Bite resistance	5.1	5.7	6.6	7.1	P<0.001	0.81
	Juiciness	4.9	7.2	6.4	5.8	P<0.001	1.11
	Tenderness	8.3	7.0	5.6	5.0	P<0.001	1.32
	Fibrousness	2.0	3.2	3.4	3.2	P<0.01	0.95
	Crumbly	6.0	4.4	3.5	3.9	P<0.001	1.53
	Chewing time	5.6	6.6	7.4	7.9	P<0.001	0.84
	Chew residual	4.7	6.7	7.4	7.3	P<0.001	1.38

As seen in Table 4.7, the LTLT technology was significantly more intense in well-done appearance and meaty flavour, higher in tenderness and crumbly texture and significantly reduced in juiciness, chewing time and chew residual. Samples treated with shock wave technology were not differentiated from the control samples on the 14 attributes. Furthermore, samples treated with shockwaves were not differentiated from brine injected samples on the attribute juiciness, for which they obtained the highest scores compared to LTLT and control samples. The taste attributes did not contribute to the overall sensory characterization of the different technologies.

Task 4.3: Influence of shock waves on shelf life and further processing abilities

Functional ability of shock waves in sausage production (deliverable 4.2)

The optimum settings of the SW-machine (task 4.1 + 4.2) were used in this study. The right and left forepart of pig were used in this trial and the meat was vacuum packed and treated twice with shockwaves. Meat from the right part was SW-treated and the left part was used as a control. Different meat batters with shoulder, jowls, fat, salt and water were made and sausages of 800 g were stuffed in casings with a diameter at 60 mm. and heated to a core temperature at 75°C, chilled and stored at 2°C for 4-6 days before analysis of yield, texture and chemical composition. The following sausages were produced of meat with or without SW-treatment:

- Lean, high NaCl (2.2-2.4% NaCl)
- Fat, high NaCl (2.2-2.4% NaCl)
- Lean, low NaCl (1.8-1.9% NaCl)
- Lean, low NaCl (1.8-1.9% NaCl)
- Lean, low NaCl, 3% soya (1.8-1.9% NaCl)

In the lean and fat sausages with high salt content (2.2-2.4% NaCl) the cooking loss was not affected by the SW-treatment. However, in sausages with low salt content (1.8-1.9%) the SW-treatment reduced the cooking loss in both the lean and fat sausages and furthermore in the sausages with added soya. In these three batches the cooking loss was reduced from 5.1% to 3.5%, from 1.7% to 0.6% and from 4.8% to 2.6% (Table 4.8). Furthermore, the texture analysis showed no differences in the strength needed for compression and no differences in slice ability were observed.

Table 4.8. Cooking loss of sausages produced from meat with and without SW-treatment.

	Right forepart, with SW		Left forepart, no SW		P-value (T-test)
	Average	Std.dev.	Average	Std.dev.	
Lean-high NaCl	6.5	0.5	7.0	0.3	P=0.012
Fat- high NaCl	1.6	0.3	1.3	0.9	P=0.178
Lean-low NaCl	3.5	0.5	5.1	0.2	P<0.001
Fat-low NaCl	0.6	0.3	1.7	0.4	P<0.001
Lean-low NaCl-soya	2.6	0.3	4.8	0.6	P<0.001

Shelf life of shock wave treated vacuum packed beef and pork (deliverable 4.3)

The optimized combination of packaging materials and processing parameters found in task 4.1 was used for studying how the shockwave technology affects shelf life of vacuum packed beef and pork. Three batches of beef (eye of round, topside, cuvette) from HIK and one batch of pork topside from HVSL was investigated. Non treated samples were used as controls. The vacuum packed meat was stored at 5°C ±1°C for up to 40 days. During storage psychrotrofic bacterial count, lactic acid bacteria, *Brochotrix termospachta*, *Pseudomonas* sp. and *Enterobacteraceae* was counted. Furthermore the amount of meat juice in the packages and sensory analysis of smell and appearance was evaluated.

The results showed that 18-26% of the packages were spoilt during treatment in the SW-machine.

The analysis of variance showed a clear effect of days and no effect of treatment. In details:

– No significant difference between control and shockwave treated meat.
– A significant increase in the number of psychrotropic bacteria, lactic acid bacteria and *Enterobacteriaceae* during storage.
– No significant change in *Pseudomonas* sp. and *Brochotrix termospachta* during storage
– A significant change in odour and visual appearance during storage.

The effect of the SW-treatment was also investigated on pure cultures. Gaze swaps (three each bacteria and treatment) wetted with 5 ml of *Pseudomonas flourescens* or *Brochotrix thermospachta* was treated in the SW-machine at the same settings as the vacuum packed meat. No effect on inactivation of bacteria was observed

During storage the amount of meat juice in the packages was measured and compared to the weight of meat. The statistical analysis showed no difference in drip loss between SW-treated and control samples of beef cuvette (P=0.0716); beef topside (P=0.0491) and beef eye of round (P=0.6524). However, the results from the test of pork topside showed that the drip loss in SW-treated pork topside was less than in the non-treated controls (P=0.0368). No crossed effect was found.

The ***conclusions of WP4*** are:

– The energy produced by the SW machine might not be as uniform as needed to detect a difference and it is not known if higher energy might have improved the effect on meat.
– SW treatment in general does not affect the colour of pork and it does not affect the drip loss in packages with fresh meat or the cooking loss (D.4.1). The tenderness is affected to a limited extent.
– SW-treatment of pork (D.4.1):
    - Reduced hardness (from 4.8 to 3.7) and crispness (from 4.6 to 3.8) for pork loin and hardness (from 6.3 to 5.5) for the outer ham muscle
    - Reduced Warner Bratzler peak shear force for both pork loin (from 43.5 to 39.3) and the outer ham muscle (from 70.7 to 50.8)

- SW-treatment of beef (D4.1)
  - Improved ratings for texture properties and reduced shear force for the flat end of the muscle of eye of round.
  - No effect on weight and cooking loss and shear force measurements for any of the ageing times for eye of round.
  - Noeffect on peak shear force values for beef silver topside aged 3, 7, 14 and 21 days.
  - Improved tenderness and reduced bite resistance compared to control samples of beef steaks from filet
  - Repeated SW-treatment on beef eye of round did not influence peak shear force values.
- Comparison to other tenderization technologies showed that (D4.1)
  - Samples treated with shock wave technolgy were not differentiated from the control samples in the sensory profile and obtained the lowest ratings on tenderness compared with LTLT treatment and brine injection.
  - Shock wave treatment is not able to compete with other tenderizing technologies regarding improvement of tenderness.
  - There was no difference between mean peak shear force values for the four treatments. This may be explained by the fact that in a sensory profile, tenderness is a complex property that covariates with other texture properties while a Warner Bratzler shear force is an isolated physical measurement that is not able to measure juiciness and therefore does not allow for the same sensory complexity as the human senses of a sensory panel.
- SW-treatment of pork for sausage production (D4.2):
  - Reduced the cooking loss in sausages with 1.8-1.9% NaCl
  - Had no effect on cooking loss in sausages with 2.2-2.4% NaCl
  - Had no effect on texture in all recipes
- The shelf life trials showed that SW-treatment (D4.3):
  - Spoils 18-26% of the packages of vacuum packed meat
  - Shelf life of vacuum packed beef and pork is not affected
  - Bacteria common to fresh meat is not inactivated
  - Does not affect the drip loss in beef
  - Reduce the drip loss in pork

WP5: Evaluation of cost effectiveness and overall estimation

Task 5.1 Evaluation of cost effectiveness

Based on the results of WP 2–4 the cost effectiveness of the shockwave technology was evaluated. By comparing the technical and financial efforts (investment and operation costs) to quality improvement and increased production efficiency the benefits of an implementation of the technique are described. To facilitate the implementation into industrial practice, cost models are derived, which can be used as a decision guideline for potential future users of the technique. The cost models are mainly based on input from WP 2, technical requirements for shock wave equipment, component and total costs, cost of operation, wear and spare part requirements, energy consumption and costs, WP 3, packaging material costs and possible extra efforts for packaging, WP 4, Quality improvement, reduction of efforts (fixed capital, space and energy) for maturation, increasing yield and quality of processed pork meat. In summary a cost model will be developed, to highlight the techniques benefits and to demonstrate associated efforts to interested further SMEs.

The detailed information is found in deliverable 5.1. A brief summary is here presented and structured in four main points:
1. Cost of shockwave technology
2. Cost of shockwave resistant packaging materials
3. The value of improved tenderness of beef and increased yield in sausages manufacturing
4. Data integration to economic models and overall discussion

1. Cost of shockwave technology

The estimate of the cost of the shockwave technology: durable cost (machine depreciation and spare parts) and operative cost (energy and water consumption, personnel cost) has been calculated. The estimation is based on actual costs for the construction of the shockwave prototype (materials and personnel cost). The costs of the spare parts have been estimated as well. It has been taken into account the real needs of spare part replacement based on the analysis of the observations obtained from operating the prototype at DTI in real conditions (see deliverable 4.1, annex I). Operative costs have been estimated based on cost for Germany. Germany represents an average European country in relation to the country correction coefficients (CCC) within the European Union. The cost of the shockwave technology can be observed in Table 5.1.

Table 5.1. Durable and operative costs of shockwave technology.

	Durable cost (€/kg)	Operative cost (€/kg)	Total (€/kg)
Throughput (540 kg/ hour)	0.16	0.04	0.20
Throughput (1800 kg/ hour)	0.05	0.01	0.06

As the throughput in the developed shockwave greatly varies [540-1800 kg/ hour], the cost of the technology varies accordingly [0.20-0.06 €/kg]. An average cost of 0.13 (€/kg) can be reasonable estimated.

2. Cost of shockwave resistant packaging materials

The estimation is based on the costs for actually used packaging material at Hvidebæk and Himmerland and cost calculations from SVE for the new developed laminates which had the best resistance to resists the shockwave treatment and can be also used as consumer package to deliver the treated meat directly to the supermarket.

Table 5.2. Calculation of packaging costs for the both new developed vacuum bags and extra costs compared to commercial bags.

Premises for calculation (based on prices for 50000 m² or 180.000 bags)				Description	Price (€/kg)	Extra costs (€/kg)
Film width [mm]	Film length [m]	Size [m²]	Weight meat [kg]			
280	500	0.28 [3)]	2	Scheyer ESB-L560 compared to commercial bag	0.247	0.172
280	500	0.28 [3)]	2	Scheyer V9100 compared to commercial bag	0.248	0.173

[3)] Size includes both sides of the bag

Table 5.3. Calculation of packaging costs for the developed thermoformable tray and extra costs compared to commercial thermoformable film.

Premises for calculation (based on prices for 10000 m² or 120.000 packages)				Description	Price (€/kg)	Extra costs (€/kg)
Film width [mm]	Film length [m]	Size [m²]	Weight meat [kg]			
422	200	0.0844 [4)]	2	Scheyer thermoformable and V9100 film compared to commercial thermoformable film	0.186	0.152

[4)] Size includes the size of the upper film or the base film (0.0844 m^2 each).

Because of the very high requirements of the SW-treatment process the materials and techniques used to design this bag are cost intensive resources which are really needed for resistance of the actually machine.

3.1. The value of improved tenderness

Miller *et al* (2001) made a national consumer evaluation on strip loin steaks of known Warner Bratzler shear (WBS) force values, ranging from tough (>5.7 kg) to tender (< 3.0 kg). In the study they assessed the monetary value that consumers place on tenderness by determining the average price that a consumer would pay for a steak in three tenderness categories. The consumer could choose between the prices: 17.14, 14.28 or 10.98 $/kg. The WBS values and Mean Price was used to estimate the value of an increased tenderness. During the trials in WP4 the tenderness was measured on a scale from 1 to 15. The tenderness was grouped and an estimate on the % increase in mean price for meat with different values of sensory tenderness was made (Table 5.4).

Table 5.4. Estimates on how much more (%) the consumer will pay if the tenderness is improved.

	Estimated increase in price (%)		
Tenderness on a 1-15 scale	Medium tender 5-8	Tender 9-12	Very tender 13-15
Tough 1-4	3%	8%	11%
Medium tender 5-8	NA	5%	10%
Tender 9-12	NA	NA	5%
Very tender 13-15	NA	NA	NA

NA: not available

Treatment in the SW-machine at max settings and 1 treatment increased the tenderness with approximately 1 point at the sensory scale (1-15). An improvement in tenderness of 1 point is not a huge improvement and it can be discussed if this will affect the price of beef at all. For comparison brine injection increased the tenderness with 2-3 point (Rosenvold, 2006) and mechanical tenderization improved the tenderness with 1-2 points. If the earnings by the slaughterhouses were to be increased the tenderization technology must be so efficient that cuts normally known as tough can be upgraded to tender with an estimated improvement of 3-4 point. The most important aspect of the improvement of tenderness is to obtain beef with a high degree of uniform tenderness. The following estimate is based on the assumption that an improved tenderness of 1 point may increase the extra value of the meat with 1% - but this assumption is questionable. When asking quality managers at the slaughter houses they reported that they do not believe that an improvement of 1 point in sensory tenderness will change the price at all!

Table 5.5. Estimates of the increased sales value of meat with improved tenderness (1 point at the tenderness scale)

Cuts	Estimated price[a)] (EUR/kg)	Improved tenderness	Extra charge (%)	Extra charge (EUR/kg)	Meat produced (kg)	Additional earnings (EUR/tonnes)
Fillet of beef	18.8	from 8 to 9	1%	0.19	1000	187.7
Tenderloin	25.5	from 11 to 12	1%	0.25	1000	254.7
Beef rib-eye	15.4	from 8 to 9	1%	0.15	1000	154.2
Roast beef	11.3	from 4 to 5	1%	0.11	1000	112.6
Beef thick flank	8.0	from 4 to 5	1%	0.08	1000	80.4
Rump of beef	11.3	from 4 to 5	1%	0.11	1000	112.6

[a]) The prices depend on the specific market for meat and therefore different prices will be relevant to different marked

3.2. The value of improved functionality of pork

The results in task 4.3 (deliverable 4.2) shows that the cooking loss during production of cooked sausages is lowered when SW-treated meat is used in the production. In lean sausages added 2.2% or 1.7% NaCl the reduction in cooking loss was 0.5% and 1.6% respectively. In fat sausages added 1.7% NaCl the reduction in cooking loss was 1.1% whereas no effect was observed in those added 2.2% NaCl. In lean sausages added 1.7% NaCl and 3% soya the reduction in cooking loss was 2.2%.

These results indicate that SW-treatment of pork for sausage production improves the water binding capacity primarily in sausages with reduced NaCl (1.7% added) and low fat content. The average value from the test is 2% less cooking loss but it depends on NaCl and fat content. Furthermore, it has to be stated that the sausages were produced with high amount of water and low amount of meat to be able to measure small differences in cooking loss. The exact reduction in cooking loss in commercial recipes is therefore difficult to estimate. But one estimate could be:

- 2% reduction in cooking loss equals 2% increased yield. This means that a yield of 100 kg from meat without shock wave treatment would increase to a yield of 102 kg when shockwave treated meat is used
- If the product is sold to 5 EUR/kg then price for 100 kg is 500 EUR. If instead 102 kg can be produced with the same raw material then the price is 510 EUR and the additional earnings are 10 EUR

4. Data integration to economic models and overall discussion

All the data are expressed as (€/kg) (see Figure 5.1), in this way it is relatively easy to derive models, differentiate between the effect of each factor and make different comparisons.

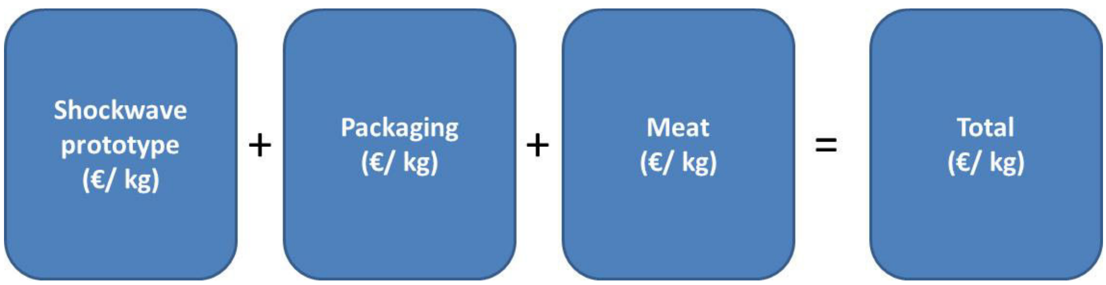

Figure 5.1. Economic feasibility scheme to evaluate the cost effectiveness of the shockwave technology.

In the Table 5.7 it can be observed the overall estimation of the costs.

Table 5.7. Integration of shockwave prototype costs, extra costs in packaging and benefits on meat.

Cost shockwave prototype (€/kg)	Cost extra-packaging (€/kg)		Benefits meat (€/kg)			Total (€/kg)
Average cost (amortization and operative cost)	Bags		Beef meat cuts			
	Scheyer ESB					
-0.13	L560	-0.172	Tenderloin	0.25		-0.052
	Scheyer V-9100	-0.173	Fillet	0.19		-0.112
			Beef rib-eye	0.15		-0.152
			Roast beef	0.11		-0.192
			Rump	0.11		-0.192
			Beef thick flank	0.08		-0.222
			Pork			
			Manufacture of emulsified sausages			
			2 % improved cooking loss	0.1		-0.202

Conclusions

- With the current technological status, the industrial application of the shockwave technology is not economically profitable at the moment. The shockwave prototype could be closer to be profitable for meat pieces of very high commercial-value and market niches of premium meats which could absorb the costs.
- The shockwave technology still needs further development to improve the throughput and to have a better interaction equipment-packaging to minimize the possibility of damaged packages which at the moment makes it greatly difficult to implement in the meat industry. Only for applications in which quality/tenderness improvement leads to higher benefits than 0.3 €/kg would make the technology profitable.
- In case of commercialization the Novel Food Legislation European Union (EC 258/97 and European Union, 5 COM (2007) 872) will need to be considered although at the moment and based on data from high pressure processing of meats its acceptance would be expected.

Potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

Baseline, performance indicators and results obtained

The following table shows the status quo of the project when started, performance indicators and the results obtained at project end.

Baseline – Status quo at project start	Performance indicator	Results obtained
No prototype available yet	→ Development of a prototype of continuous shock wave equipment including a meat handling system.	A prototype for continuous treatment is available.
Electrodetonative shock wave available at DIL with high intensity on a small reaction area induces high damaging potential	→ Development of a shock generation unit with sufficient working area.	A prototype for continuous treatment is available. Throughput of 500-1800 kg/ hour and all regular pork and beef pieces can be processed.
Scale of durability of several components of equipment is unknown	→ Evaluation of equipment durability: During long-term operation the durability of electric as well as mechanic components will be evaluated. Mechanical stress induced erosion and fatigue of components such as the shock wave actuator, fittings as well as the meat handling system will be observed and design guidelines be derived.	Done, certain pieces in the treatment area are susceptible to damage.
For cost reasons, the use of meat has to be minimized and if possible substituted by a model system with comparable properties	→ Evaluation of equipment durability: Selection of a suitable model system for packaging tests. To limit meat usages as well as to allow a standardized treatment of packaging material for analysis of resistance against shock waves a suitable model for meat is required. A gel of polymers with similar properties with meat will be identified and used.	A meat substitute based on gelatine has been developed.

No suitable packaging material available yet	→ Development of suitable packaging material for shock wave treatment (e.g. vacuum package or flexible packaging)	Partially achieved. This is an on-going and long process in the avant-guard of packaging materials.
The effects of shockwave treatment on packaging properties is unknown	→ Characterization of shock wave effect on mechanical properties, permeation of oxygen and water vapour, migration of undesired substances from the packaging material and changes of chemical parameters.	No differences in barrier, migration and mechanical properties are observed after shockwave treatment.
Limited knowledge on high pressure induced changes of packaging material properties is already available	→ For cost optimization of the packaging material this knowledge will be used to select suitable polymers for shock wave treatment.	More knowledge is now available.
Until now, shockwaves are only very preliminary tested on one single beef cut and not on pork	→ Finding optimal process parameters for the application of shock waves to improve the ageing process of pork and beef.	Studies with pork and beef have shown certain tenderness improvement.
Shockwaves have not been tested on packaged meat	→ Application of optimal packaging material and process parameters to enable a shock wave treatment to improve ageing of beef and pork	Maturation has not been accelerated in the conditions assayed (old cows).
The effect of breed, biochemical properties and pre-processing before shockwaves is unknown	→ Finding optimal meat cuts, species, animal age, sex, speed of chilling, hanging type and classification type for optimal ageing,	Partially achieved. This is an on-going and long process as the possible combinations are many.
Shockwave technology has not been compared to other tenderness enhancing operations	→ Compare shock waves to other tenderness improving technologies (such as brine injection and LTLT treatment)	Shockwave can tenderize meat similarly to blade tenderization but less than brine injection or low temperature long time cooking.
The effect of shockwaves on quality, functionality and shelf-life of meat is	→ Testing of yield, water holding capacity, colour, taste, tenderness, juiciness and microbial counts during	Shelf life, microbial growth and drip loss in fresh meat, are not

unknown.	storage	affected by shockwave treatment.
Shockwaves as pre-activator in sausage production has never been shown.	→ Testing of increased water binding, increased gelation and possibility of sodium reduction in processed meats	Yield is improved by 2 % in low added salt sausages (1.8 %)
No cost-benefit analysis of continuous shockwave equipment available yet	→ Estimation of cost effectiveness of shock wave application in the meat industry producing beef, pork and processed meat.	With the current technological status of the technology, the industrial application of the shockwave technology is not economically profitable at the moment.

The ***potential impact*** (including the socio-economic impact) is organised according to the three core R&D activities (i.e. shockwave technology, shockwave-resistant packaging materials and meat quality):

1. Contribution to advancement of knowledge / technological progress of the developed shockwave technology

The aim of the research project was to allow a commercial use of a physical technique to achieve disintegration of biological tissue by electrohydraulic shock wave application. Only by development of continuously operable equipment with sufficient working area and treatment capacity for industrial applications an industrial exploitation of the technique can be achieved. A continuous shockwave prototype has been designed and constructed by DIL which is able to process 500-1800 kg of regular meat pieces of pork and beef per hour. This prototype has been tested in semi-industrial conditions at DTI to demonstrate the industrial feasibility and economic efficiency of the technique and enabling a commercialization of the technique by the engineering SME involved.

Besides the evaluation of shockwave generation principles, interactions between process and product have also been investigated. Despite significant advances has been generated, the shockwave technology still needs further development to improve the throughput and to have a better interaction equipment-packaging in order to minimize the possibility of damaged packages which at the moment makes it greatly difficult to implement in the meat industry. Only for applications in which quality/tenderness improvement in meats leads to higher benefits than 0.3 €/kg would make the technology profitable (deliverable 5.1).

Making use of a novel, highly developed technique additional application and sales fields for the engineering SME involved as well as equipment and peripherals manufacturers can be created. From an engineering point of view, the technical progress include knowledge on the pressure distribution of the shockwave, the electrical fundamentals of the shockwave generation, the durability of components, conveyor belts under mechanical stress, scale-up guidelines as well as the requirements for a successful and safe industrial operation within an industrial environment has been created.

In addition, besides the use of the technique in meat processing, the technical progress achieved within the project facilitate its use in other industrial branches, e.g. food processing, chemical engineering, mining or recycling. The potential of the shockwave technology is high but still requires further research to transfer the technology into profitable applications.

2. Contribution to advancement of knowledge / technological progress of the developed packaging materials

Compared to other competing producers of packaging materials the development experience of SVE is significantly advanced because of his participation in the shock wave project. This advance and the personnel contacts with PFV during the development of the shock wave technology will provide SVE a promising position on the market. SVE has now the opportunity to serve the market for packaging material for shockwave application. Because at the moment there is no appropriate composite bag available at the market that withstands the shockwave process, SVE gains an advantage in technology by developing the highly puncture resistant composite materials. By enhancement of the shockwave technology, the knowledge gained in the project can be used to get fast output in new projects. In addition, the findings achieved during the development of the new packaging materials during this project can be used for the construction of new composite materials with very high puncture resistance, whereas SVE is able to serve the actual market and to develop a market.

The data generated in this project, especially the mechanical characterization, are very useful for SVE, because such data are not standard for composite or monolayer packaging films. Moreover it was important to find out the parameters that describe the mechanisms of the damaging of the composite during shockwave treatment. This will aids in the future to produce more resistant composite materials.

The application area of composites with high impact resistance in packaging is high and ranges from processes with very high mechanical stress such as shockwave or high pressure treatment (HIPP), to packaging for sharp edged foods, like bones or mussels up to big packs and bags for the construction market that have to be very robust. The advantage of the packaging materials developed in this project is that they are adequate for food contact and therefore can be easily “down-graded“ for the non-food market. However, application areas in medical technology or the pharmacy industry are conceivable, since also there, high demands are requested from packaging materials. Especially the non-significant differences in mechanical properties of the new composite materials before and after shockwave treatment show a very high resistance to long lasting mechanical loads particularly for products with long shelf life.

Another advantage in the development of the composite films is the very high seal bond strength and the very good seal ability, because they can be used for the packaging of heavy weights and for sensitive products that need a good integrity of the packaging materials. Because of the high oxygen barrier in addition the packaging materials developed increase product safety. The mechanical data gained within the project for monolayer films, are a very good basis for further packaging development of thermoforming films with high puncture resistance and tensile strength. Especially for thermoforming films very high mechanical resistance is requested, so that the packaging material does not break after falling from big heights.

Additionally, to meet the trend of minimizing packaging material, the data gained will help in the development of composite materials with high puncture resistance, but lower film thickness. Therefore the project enabled SVE to develop vacuum bags that withstand the shockwave process and that can be used for further applications in food technology. In addition the know-how SVE gained during the project will help the company in the future for further packaging development.

3. *Contribution to advancement of knowledge / technological progress of the studies on the effect of shockwave technology on meat quality*

Accelerating meat tenderization and reducing maturation time were the fundamental advantages relying on the project. This would add value to low quality beef and allow the production of a higher amount of high quality beef cuts and provide significant economic benefits and a more sustainable use of beef carcasses. By a reduction of maturation times the requirement for chilled storage capacities, energy costs as well as fixed capital costs can be reduced.

By using shock waves the time requirement for meat ageing decreases. Meat producers will benefit by a reduction of processing costs and quality improvement. The reality is that the meats submitted to shockwave were old dairy cows which were identified by the SMEs as a targeted application. The result showed a certain tenderness improvement but the maturation was not accelerated. At the moment the reason for this is unknown but maybe linked to the high collagen amount in this type of meats which is not improved by maturation. Other studies in the literature have shown that collagen structures are affected by shockwave [Zuckerman et al., 2013, Meat Science, 95, 603-607] but in the present experiment this seems not to be the case. Meat ageing is a rather complex phenomena that rely on enzymatic and biochemical actuations which still is not well understood and less when applying novel technologies such as shockwave. An instantaneous tenderness improvement has been observed by a reduced cutting force. This improvement varies between 10-20 % depending on the particular meat and is correlated with a relatively low up-grading appreciation by the consumer (1 point in a scale of 15 points). If the shockwave technology in the future can increase the tenderness of beef with 3-4 point then it will be possible to improve the eating quality of low grade cuts so then can be up graded to high value cuts. This perspective has an enormous potential for the meat industry.

Furthermore, other important information obtained is related to the effect of shockwave on shelf-life of meat. The present studies have revealed that there is no impact of the technique on the microbial florae as well as in the drip loss upon storage. It seems that the energy formed by the SW machine did not inactive bacteria or affect the drip loss in vacuum packed beef cuts of eye of round, topside or cuvette. With the energy employed it is not possible to use shock waves as a decontamination method but it is not discarded that other conditions could have certain effect.

Finally, in pork, some meat cuts like fore-end, head, shank, neck and jowl are often used for further processing i.e. in sausages or other emulsion type products. Since shockwave are impacting on the myofibrillar structure, it might be possible to use the technique as a pre-activator of the meat before sausage production in order to improve functionality. The investigation has revealed that the treatment by shockwave of raw meat results in cooked sausages with relatively higher yield. The reduced cooking loss is approximately 2% in lean sausages added low salt (1.8 %) and the recipe used is based on low meat content and high water content to be able to measure any differences. In the recipe added 2.2% NaCl no significant difference in yield was observed. For this reason the exact reduction in cooking loss in commercial recipes is therefore difficult to estimate, they might be between 0% and 2%. This fact is interesting for the meat industry but the results must be confirmed with additional investigations to ascertain whether shockwave treatment is a suitable method to improve the yield in sausage production and potentially permit a salt reduction.

WP6: Demonstration

It is very important to demonstrate in a very practical manner the potential of innovative technologies to the industry/SME. The prototype of the shockwave technology developed in the project was demonstrated to possible customer from the meat industry, packaging industry, catering, trade organizations and education in two demonstration days organized in Denmark and Germany (deliverables 6.1 and 6.2).

During the demonstration days the operation mode, the added value of the technology on the meat products and how the technology influences the sensorial quality were demonstrated. The demonstration day in Denmark focused in meat business meanwhile the demonstration day in Germany focused in packaging and machine development. Power point presentations from the demonstration days can be distributed on request.

In general, the industry was a little disappointed about the results and the technology due to the very clear fact that more development is needed to make the technology profitable. The attendants participated with high interest but questioned the benefits of investing in the shockwave technology due to the loud noise during running, the many spoilt packages during processing and the limited effect on tenderisation. The investigation of the use of the shockwave technology in other matrixes and as a decontamination technology was also suggested by the participants.

WP7: IPR management and dissemination

The project has been extensively disseminated in many ways and in many geographic locations within Europe and worldwide (deliverable 7.3 and 7.5, and tables below with list of dissemination activities). For its impact and audience it can be remarked the followings:

Two scientific publications in the highest ranked journals related to Meat Science:

1. Bolumar, T., Bindrich, U., Toepfl, S., Toldrá, F., & Heinz, V. (2014). Effect of electrohydraulic shockwave treatment on tenderness, muscle cathepsin and peptidase activities and microstructure of beef loin steaks from Holstein young bulls. Meat Science (submitted).
2. Bolumar, T., Enneking, M., Toepfl, S., & Heinz, V. (2013). New developments in shockwave technology intended for meat tenderization: opportunities and challenges. A review. Meat Science, 95, 931-939.

Two plenary sessions in the most important international conferences in Meat Science and Technology:

1. Shockwave Technology. ShockMeat: a European project addressing shockwave technology for meat tenderization. Quality, packaging and economic implications. Invited speaker for plenary session. 67th AMSA Reciprocal Meat Conference. Wisconsin-Madison, USA, 15-17th June 2014.
2. New developments in shockwave technology intended for meat tenderization: opportunities and challenges. Invited speaker for plenary session, Hot Topics. 59th International Congress of Meat Science and Technology (ICoMST). Izmir, Turkey, 19-23th August 2013.

Several dissemination papers in journals with readership addressing industry and industry association in sectors such as food, packaging, biotechnology and pharmaceutical industry has been done. The shockmeat project has also disseminated in the website which has received a total of 9073 visits since July-2013 till June 2014 and an average of 20-30 visits per day has been registered. The website includes a link to the video produced to disseminate the shockmeat project in an attractive manner.

Historical perspective of shockwave technologies for meat tenderization

In 1970, Godfrey patented a method and apparatus for tenderizing food including meat by the use of an explosive charge that generates a shock wave and called it, hydrodynamic pressure processing (HDP). Then, Long (1993 and 1994) modified the technology to overcome deficiencies and called it, Hydrodyne® process. The Hydrodyne® process has been extensively investigated by Professor Morse Solomon from the Food Technology and Safety Laboratory (Beltsville, MD, USA) showing important improvements in meat tenderness. However, the generation of shockwaves by explosives carry some important disadvantages and technical challenges in terms of equipment development, potential contamination with residues from the explosion and safety issues for operators.

During the period (2008 to 2011) and within a German research project, a pilot plant for the generation of shockwaves intended for meat tenderization by electro-hydraulic underwater discharges was designed and realized at the German Institute of Food Technologies (DIL). The pilot plant relied on underwater discharges of electric energy between two electrodes mediated by an aluminium wire. A prototype with an average power of 2 kW and a peak power of 40 kW with a vessel volume of 50 l was developed. An effective energy conversion from electrical to mechanical energy was achieved and demonstrated to be effective to tenderize meat. The developed equipment was successfully used to decrease the maturation time for beef cuts from 14 to 7 days. The shockmeat project has developed an industrial prototype for continuous shockwave treatment. This prototype tries to overcome the limitations detected in the first prototype built at DIL and fulfil the robustness required in industrial environments and is oriented for a continuous treatment of the meat rather than a batch system.

Exploitation of results

Based on the results obtained throughout the project and the analysis carried out to evaluate the cost effectiveness and overall estimation (deliverable 5.1) the following conclusions are reported:

- With the current technological status of the technology based on trials and research with a prototype executed with DIL typology power generator, the industrial application of the shockwave technology is not economically profitable at the moment. The shockwave prototype could be closer to be profitable for meat pieces of very high commercial-value and market niches of premium meats which could absorb the costs.

- The shockwave technology still needs further development to improve the throughput and to have a better interaction equipment-packaging to minimize the possibility of damaged packages which at the moment makes it greatly difficult to implement in the meat industry. Only for applications in which quality/tenderness improvement leads to higher benefits than 0.3 €/kg would make the technology profitable.

- In case of commercialization the Novel Food Legislation will need to be considered although at the moment and based on data from high pressure processing of meats its acceptance would be expected.

Exploitation of the developed shockwave technology

A continuous shockwave prototype has been designed and constructed by DIL which is able to process 500-1800 kg of regular meat pieces of pork and beef per hour. This is the only shockwave prototype in Europe of this size to the best of our knowledge and thus represents a unique installation for testing and research. The involved SME, Promatec, can use the prototype as a foundation to develop it further till make an industrial application. Joint ventures will be pursued by the involved SMEs to develop the technology.

Exploitation of the developed shockwave-resistant packaging materials

At the moment there is no shockwave-resistant packaging material in the market. The packaging materials developed by Scheyer and OFI represent advanced materials in its nature. The demand of high resistant packaging materials is high in the industry as many processes require high mechanical resistance. Mainly the packaging SME involved, Scheyer, can make use of this knowledge to put in the market high resistance packaging materials with a position of competitive technological advantage.

Exploitation of the studies on the effect of shockwave technology on meat quality

The results of the treatment of meats by shockwaves showed that the developed shockwave prototype cannot produce shock waves which can improve the tenderness of beef to an extent where an added value can be charged.

Future development of shock wave technology will have to focus on the following aspects if shock waves should be used in the meat industry:

- Less noise and vibration during running the machine.
- Increased capacity so much more meat can be treated per hour.
- Improving the hygienic design, so cleaning becomes easier.
- Further improvement of the packaging material so the amount of broken packages is reduced to zero in combination with machine parameters and process optimization
    - Avoid burning/hot particles from the machine.
    - Improve shock wave resistance of the packaging material.
- Better improvement of tenderness than what obtain with the prototype.
- Further studies to document how shock waves can increase cooking yield in low salt sausages and other proceeds meat.
- Additional testing to investigate which conditions lead to tenderness improvements (number of pulses, repeated treatment, treatment on upside and downside,..)
- Additional testing to investigate which meat cuts (age, breed, sex) are most susceptible to be manipulated by shockwave treatment including animal (beef, pork, turkey, chicken,..).

At the moment the meat SMEs cannot use the results directly on their production lines as further development of the method is needed. They are up-to-dated on shockwave technology and other tenderizing methods.

Address of the project public website and relevant contact details

Address website: http://www.shockmeat.eu/

Relevant contact details:

Partner		Contact person
SMEs		
Promatec Food Ventures (PFV)		Mark de Boevere
Himmerlandskød A/S (HIK)		Søren Andersen
HvidebækSlagteri A/S (HVSL)		Peter Søgaard
Scheyer Verpackungstechnik (SVE)		Jürgen Wiesenegger
RTDs		
German Institute of Food Technologies (DIL)		Stefan Töpfl and Tomas Bolumar
Danish Technological Institute (DTI)		Anette Granly Koch
Austrian Research Institute for Chemistry and Technology (OFI)		Mike Krainz