

Review article

Oyster shucking technologies: past and presentDaniel E. Martin^{1*} & Steven G. Hall²¹ United States Department of Agriculture, Agricultural Research Service, 2771 F&B Road, College Station, TX 77845, USA² Department of Biological and Agricultural Engineering, LSU AgCenter, Baton Rouge, LA 70803, USA*(Received 2 February 2004; Accepted in revised form 11 August 2004)*

Summary A review of oyster shucking technologies from the nineteenth century to the present day is presented, comparing advantages and disadvantages of various mechanical, thermal, pressure and other technologies.

Keywords Bioprocess, bivalve, engineering, heat transfer, mollusc, post-harvest, shelf-life, shellfish processing, steam.

Introduction

A variety of oyster shucking technologies have been used since ancient times. In the last 50 years, however, the number of inventions and innovations in this field has dramatically increased. This paper provides a review of over one hundred patents and innovations in areas including mechanical, electrical, thermal, chemical and other technologies. This review reveals that recent advances in instrumentation and control technologies in the food engineering arena have opened up new opportunities in this field, pointing toward technologies that are effective, inexpensive and safer than previously available technologies. Advances in this particular field may also be applicable to other food engineering specialties.

A review of oyster shucking technologies

For centuries, oysters have been a tantalizing delicacy. It has been documented that oysters were eaten in vast numbers by prehistoric man on the shorelines of Scandinavia more than 5000 years BC (Larsen *et al.*, 1957). Artificial oyster beds existed in China long before the Romans and Greeks began to cultivate them, although the Chinese preferred to eat their oysters dried instead of raw (Philpots, 1890). However, the Romans are

most noted for their infatuation with oysters 2000 years ago (Eyton, 1858). The Romans were so fond of their oysters that they frequently sent slaves to the shores of France and the English Channel to harvest them and bring them back in barrels (American Mussel Harvesters Inc., 2003). They also used pack horses to carry their harvested oysters from the northern European coasts across the Alps, packed deep in baskets of ice, snow and hay (Stott, 2003). But this love affair with oysters came with its own set of challenges. As Henry Ward Beecher wrote: 'An oyster, that marvel of delicacy, that concentration of rapid excellence, that mouthful before all other mouthfuls, who first had faith to believe it, and courage to execute? The exterior is not persuasive.' (Polansky, 2003). Although prized for their taste, oysters are difficult to open and from that time forward, the quest has been on to design a better way to shuck an oyster (Tables 1 and 2).

Oysters are composed of two calcareous valves or shells wherein the soft body of the oyster lies (Fig. 1). The left valve is usually cupped and has a projection at the anterior region that curves upward called the umbo. The oyster normally rests on the left valve. The right valve is usually less cupped and more flat in appearance. The valves are joined by a resilient lamellar ligament at the anterior margin of the oyster. This ligament is biased in the open position and counteracts the force of the adductor muscle which closes the valves. The ligament goes into tension when the

*Correspondent: Fax: 979 260 9386;
e-mail: dmartin@apmru.usda.gov

Table 1 Mechanical methods of oyster shucking. Numbers refer to patent numbers. Designs are indicated by D or Des. Publications are identified by author and date.

Mechanical											
	Wedge		Slice		Pry		Notch	Muscle/ Shell Separator	Shear	Freezing/ Impact Shock	Crush
	10,810	3,583,026	10,798	715,988	10,798	19,050	19,050	19,050	210,032	3,007,801	115,474
	19,050	3,685,097	10,810	829,353	75,917	112,895	402,867	2,473,609	3,037,237	4,198,728	
	34,495	3,706,114	75,917	829,693	98,102	133,267	1,445,672	2,476,962	3,528,124	4,312,099	
	115,474	3,748,692	98,102	1,232,682	112,895	144,063	1,857,872	3,440,684	4,532,677	D282,076	
	332,403	3,964,130	112,895	1,352,108	133,267	159,598	2,337,188	3,988,805	4,992,289		
	545,329	3,991,466	115,474	1,445,672	159,598	162,606	2,391,739	4,143,444	5,059,151		
	896,162	4,059,870	133,267	2,354,928	162,606	211,449	2,608,716	4,304,029			
	1,041,198	4,069,552	159,598	2,391,739	177,138	332,403	2,652,588	5,005,258			
	1,060,502	4,133,078	162,606	2,854,688	191,384	408,939	2,818,598				
	1,071,352	4,348,788	177,138	3,548,450	390,759	411,381	2,823,414				
	1,445,672	4,393,546	191,384	3,846,908	408,939	411,797	2,832,989				
	1,465,799	4,477,943	332,403	4,133,078	411,381	469,312	2,929,502				
	1,597,622	4,610,052	D368,210	4,787,123	411,797	545,329	3,007,801				
	1,679,787	4,617,734	D386,362	5,145,448	469,312	708,014	3,037,237				
	1,857,872	4,674,154	390,759	5,599,228	708,014	715,988	3,230,578				
	1,990,424	4,796,333	402,867	6,398,635	715,988	829,353	3,258,124				
	2,000,075	4,870,719	408,939	6,503,137	829,353	1,007,411	3,320,631				
	2,136,816	5,178,577	411,381	Des.307,374	829,693	1,117,984	3,594,860				
	2,354,928	5,214,812	469,312	Des.307,375	896,162	1,232,682	3,958,763				
	2,391,739	5,288,263	708,014		1,232,682	1,314,465	4,018,389				
	2,473,608	5,334,080			1,352,108	1,510,313	4,309,793				
	2,506,817	5,401,208			1,445,672	2,854,688	4,551,886				
	2,609,565	5,403,230			1,472,179	2,942,292	4,663,805				
	2,691,794	5,482,500			2,854,688	3,037,237	5,005,258				
	2,747,220	6,110,031			3,846,908	3,548,450	5,613,904				
	2,808,613	6,190,248			4,787,123	3,934,311	5,788,542				
	3,440,684	6,244,948			5,145,448	4,503,137					
	3,548,450				5,216,812	5,399,117					
					6,398,635	Des.307,374					
					6,503,137	Des.307,375					
					Des.307,374						
					Des.307,375						

oyster is closed and into compression when the oyster is in the relaxed state and open.

The adductor muscle is composed of two different types of muscle. The majority of the adductor muscle is translucent and obliquely striated. This muscle is fast acting and provides protection for the oyster. It also helps expel pseudofaecal material from the mantle with a rapid closing motion (Hedeen, 1986). Sessile intertidal bivalves such as oysters frequently remain closed for long periods of time. Thus, to the side of the translucent muscle, there is a smaller, crescent-shaped muscle with smooth muscle fibres and opaque in colour that holds

the valves closed for extended periods of time (Kennedy *et al.*, 1996). Both of these muscle types are attached to the inside of the shell on both the left and right valves. The strength of this opaque muscle is what makes it difficult to open an oyster.

Shucking an oyster involves not only separating the shells of the oyster but also severing or causing a release of the adductor muscle from these valves. The early Romans used a triangular punch, which, although it caused separation of the shells, introduced grit into the edible portion of the oyster (Taylor, 1983). In the mid-1800s, the oyster knife was invented and its many variations and modi-

Table 2 Non-mechanical methods of oyster shucking. Numbers refer to patent numbers. Publications are identified by author and date.

Thermal					Pressure			Electrical High Frequency
Steam	Flame	Infrared Radiation	Microwave	Laser	High	Low Pressure Steam	Chemical Mg+	
2,008,820	2,047,688	Wheaton (1971)	3,585,676	Singh (1972)	2,102,943	Martin (2004)	Namba <i>et al.</i> (1995)	3,070,834
2,047,688	2,337,188	4,951,356	4,420,492		2,102,945			
2,102,943	3,230,578				3,128,496			
2,102,945	3,564,648				3,174,180			
2,608,716	3,566,438				3,964,130			
2,652,588	3,594,860				4,313,241			
3,465,382	4,691,412				4,383,348			
4,141,114	4,924,555				4,524,681			
4,524,681					4,569,850			
4,616,625					5,112,269			
5,112,269					6,217,435B1			
Martin (2004)					6,393,977B1			
					6,426,103B2			
					6,537,601B1			

fications have developed since (Blake, 1854; Huffnagle, 1868; Pattberger, 1869; Boyer, 1871; Starin & John, 1872; Berger, 1874; Megee, 1874; Lum & Sanford, 1876; Temple, 1877; De Lamarre, 1888; Huppmann, 1889; Thompson, 1889; Wood, 1892; Blangden, 1902; Cooley & Bishop, 1902; Colford, 1906; Rand, 1906; Hartleb & Hartleb, 1917; Arthur, 1920; Lofland, 1923). The oyster knife is still the standard today as it allows for inexpensive access to the oyster. It is good for prying the shells loose at the hinge and severing the adductor muscle. Some shuckers use a hammer in conjunction with the knife to crack the bill of the oyster so the knife can be inserted more easily. As there is no heat involved in the process, the final product also remains in a raw state. However, this method of shucking requires skilled labour so that the oyster is not cut as the muscle is severed. Failure to exercise caution when severing the adductor muscle may result in yield loss as the oyster is cut and 'bleeds'. In addition, shucking by knife is labour intensive and as labour costs increase and qualified shuckers become harder to find, profit margins may be reduced.

From the mid-1800s to the mid-1900s inventors, realizing how difficult manual shucking was, designed lever-operated oyster shucking devices to assist with this task (Table 1). The typical arrangement was a lever with a wedge-shaped

implement attached to it whereby the oyster would be placed on a platform of varying designs; the lever would be drawn down with the wedge inserted at the junction of the two shells and force applied (Towers, 1854; Seipel & Rupp, 1858; Hawkins, 1862; Holtzmann, 1871; Heimlich, 1878; Leduc, 1885; Steuart, 1889; Carlson, 1907; Roters, 1908; Tiffany, 1912; Schmidt, 1913; Asklar, 1923; Richens, 1926; Hallock, 1935; Frazier, 1938; Svec, 1950; Mostowicz, 1952; Thompson, 1956; Palmere, 1957; Rey, 1960; Coccellato, 1969; Helmer, 1970; Peoni, 1971). If positioned correctly, this wedge would separate the two shells. Although the shells would be separated, the muscle would still be attached to the shells and a traditional oyster knife or other means would be needed to sever the muscle from the shells. Although the mechanical advantage of the lever made the task easier, only one oyster could be opened at a time. Also during this same time period, notching devices were designed that cut an opening in the shell so that a knife could be easily inserted (Seipel & Rupp, 1858; Boyer, 1871; Starin & John, 1872; Cleary, 1873; Berger, 1874; Megee, 1874; Wells, 1879; Leduc, 1885; Farrell, 1889; Huppmann, 1889; Thompson, 1889; Wood, 1892; Zucchini, 1895; Blangden, 1902; Cooley & Bishop, 1902; Rand, 1906; Zimmers, 1911; Dandridge, 1914; Hartleb & Hartleb, 1917; Buras, 1919;

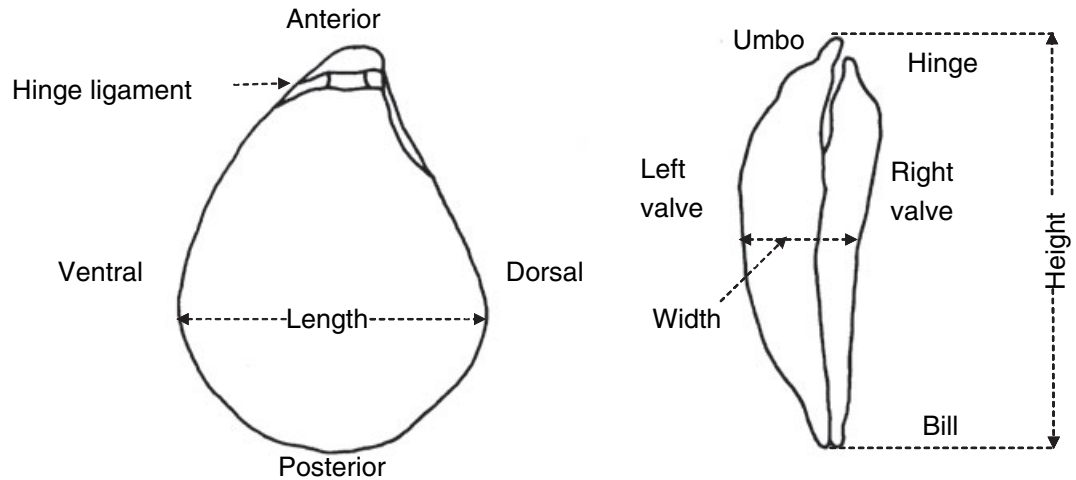


Figure 1 Diagram depicting anatomical features and the height, width and length of an oyster.

Dickerson, 1924; Colangelo, 1958; Rey, 1960; Lapeyre *et al.*, 1962; Helmer, 1970; Thompson, 1976; Li & Wheaton, 1992; Telford, 1995; So & Wheaton, 2002).

In 1907, the first recorded patent was filed on a machine that automatically notched and separated the shells, severed the meat, and separated the shells from the meat (Torsch & Parker, 1907). While these machines produced a mechanically shucked raw oyster, the main drawback of these machines was that the yield was likely to suffer from imprecise severing of the adductor muscle. In addition, they failed to address what would later emerge as a national concern, food safety. From this point on, however, many automated, multi-function machines were invented to mechanically shuck oysters (Egli, 1923; Doxsee & Cook, 1935; Jenkins, 1936; Cook, 1937; Doxsee & Cook, 1937; Geldermans & de Hond, 1943; Doiron, 1949; Harris, 1952, 1953, 1958; Seal & Harris, 1958; Skrmetta, 1958; Harris, 1960; Lapeyre *et al.*, 1961, 1962; Marvin & Henderson, 1966; Brown, 1967; Meyer, 1969; Wenstrom & Gorton, 1970; Nelson *et al.*, 1971; Snow, 1971a, 1971b; Martin, 1976; Carlson, 1979; Cox, 1979; Cohen, 1980; Twuyver & Johnson, 1980; Cox, 1981; Cohen, 1982; Martin, 1982; Wenstrom & Gorton, 1985; Brown, 1987; Gifford, 1990; Griffis, 1991; Kiczek, 1991a, 1991b; Petersen & Sorensen, 1992; Earnshaw, 2000). Recent improvements in machine vision may allow identification of oyster hinge lines (Li &

Wheaton, 1992; So & Wheaton, 2002) which could then be used in conjunction with other automated mechanical processes to more effectively automate the mechanical shucking process.

Thermal and other methods were developed in the last century (Table 2). The first steaming operation for shucking oysters was recorded in 1935. Heat has long been known to relax the adductor muscle. Doxsee & Cook (1935) steamed oysters in a unit that contained two compartments so that one could be steaming the oysters while the other was being loaded. They steamed the oysters for 20 min and then ran them through a series of conveyor belts and diverting members which separated the shells from the meat. Although this process accommodated many oysters at a time and was very successful at opening the shells and releasing the meat from the shell, it also cooked the oysters. The end product for these types of processes was meat that was used for canning. Many other inventions followed that successfully utilized steam for shucking oysters (Jenkins, 1936; Cook, 1937; Doxsee & Cook, 1937; Harris, 1952, 1953; Meyer, 1969; Carlson, 1979; Harris & Smith, 1985; Froome, 1986; Petersen & Sorensen, 1992; Martin, 2004). Although most of these were used prior to canning, when cooking of the oysters was acceptable, one steaming operation for shucking scallops was claimed to produce a 'fresh' product (Meyer, 1969). Meyer propounded the use of a mobile and compact steaming operation that

could be installed on boats so the scallops could be shucked immediately after harvest for the raw market. The scallops were passed under steam jets to open them and then were dropped onto an agitated screen which separated the meat from the shells.

Other heating methods were also developed. Snow (1971a) patented a dry heat process whereby bivalves were exposed to 800 °F or higher heated gas for an undisclosed amount of time. (It is assumed that this was for a matter of seconds to eliminate cooking). The patent claims that this high temperature and short treatment time resulted in an uncooked shucked mollusc. A second patent (Snow, 1971b) incorporated a method of crushing and separating the shells from the meat in addition to the shucking operation. Nelson *et al.* (1971) combined dry heat from a burner to sever the muscle from one half of the shell, with the physical separation of that shell followed by water jet separation of the muscle from the remaining shell.

With the commercialization of microwave devices in the late 1960s came the opportunity to investigate the practicality of applying this technology to oyster shucking. Spracklin (1971) found that controlled exposure of bivalve molluscs to microwave radiation effected a gaping of the shell without cooking. The adductor muscle could then be severed manually with an oyster knife, thus facilitating the shucking process but not eliminating the manual separation of the muscle from the shell. Another application of microwave energy to oyster shucking (Taylor, 1983) directed focused microwave energy on the anticipated location of the adductor muscle. This caused the release of the muscle from the shell and maintained a raw product. The oysters, however, were not treated *en masse* and had to be positioned so that the microwave energy could be concentrated directly over the anticipated location of the adductor muscle. In addition, as with previous designs, the microbiological safety of the oysters was not addressed.

Other emerging technologies were investigated in the late 1960s and early 70s. Gaping of oyster shells by high-intensity shock waves was tried by Paparella & Allen (1970) with some success. They reported an 87% gaping efficiency but noted evidence of shattered tissues in many of the oysters. The severing of the adductor muscle using infrared radiation to destroy the collagen connect-

ing the adductor muscle to the shell was investigated but found also to partially cook the oyster in the process (Wheaton, 1971). Singh (1972) utilized laser technology to sever the adductor muscle with good success. He achieved nearly 100% gaping efficiency while keeping the oysters in a raw state. He was able to direct the laser beam at the location of the adductor muscle and apply heat with pinpoint accuracy to effect detachment. This method required much less heat energy and could be commercialized with proper sorting according to size and a positioning device for the oysters. Initial tests with a 70 watt laser caused gaping in 30–60 s. Current higher power lasers could reduce that time substantially and may be more economically feasible now than the lasers used for the study. Coupling one of these focused energy applications with recent advances in image processing (Li & Wheaton, 1992; So & Wheaton, 2002) could result in a high throughput, safe and effective automated system which avoids some of the drawbacks of previous systems.

Since the 1970s, increased attention has been focused on the safety of eating raw oysters (Acton, 1970; Peixotto *et al.*, 1979; Phillips, 1979; Garcia, 1980; Sobsey *et al.*, 1980; Chin *et al.*, 1987; Ford, 1990; Beecham *et al.*, 1991; Cook & Ruple, 1992; Lefkowitz *et al.*, 1992; Murphy & Oliver, 1992; Ruple & Cook, 1992; Tamplin & Capers, 1992; Anonymous, 1993; Klontz *et al.*, 1993; Groubert & Oliver, 1994; Sun & Oliver, 1995; Chen, 1996; Hlady & Klontz, 1996; Cook, 1997; Hlady, 1997; Jackson *et al.*, 1997; Shapiro *et al.*, 1998; Andrews *et al.*, 2000; Keithly & Diop, 2001; Lorca *et al.*, 2001; Nguyen *et al.*, 2001; Cook *et al.*, 2002; DePaola *et al.*, 2003; Lee *et al.*, 2003). Pathogenic bacteria are known to naturally occur in the waters where oysters are seeded and harvested. During the summer months, these bacteria increase in number as warmer waters favour their growth. As a filter feeder, oysters ingest and retain these bacteria. Most people are unaffected by consumption of raw oysters which have been harvested from approved shellfish growing waters (Anonymous, 2001). A small percentage of the population with medical conditions that result in compromised immune systems, however, die each year from the consumption of raw oysters. With this in mind, it has become important to develop processes to eliminate harmful bacteria from oysters intended for the half shell

market. Additionally, safety during processing, while not well documented, is necessary to avoid injuries or infection (Beecham *et al.*, 1991) of oyster shucking personnel.

While many of the shucking methods used up to today have shown promise in one or more areas of functionality, none has been able to economically shuck oysters on a commercial scale while maintaining a raw product. In recent years, however, a process has been developed that addresses these needs, while apparently eliminating pathogenic bacteria (Voisin, 2003). The process calls for 100–800 MPa (approximately 10 000–100 000 psi) of hydrostatic pressure to destroy pathogenic organisms and separate the adductor muscle from the shell. The process claims to triple the shelf-life of the final product. Oysters are placed in a cylinder with water and pressurized to a predetermined isostatic pressure for 1–15 min with temperature rises constrained to between ambient and 150 °F. It is theorized that the process reduces pathogenic bacteria below detectable levels by modifying the bacterial cell membrane's permeability. As a result, the bacteria are inactivated or die. It is claimed that the hydrostatic process has little to no effect on the taste, texture or nutritive value of the processed oysters, although recent studies (e.g. Cruz-Romero *et al.*, 2004) suggest some changes in colour, pH and biochemistry. The release of the adductor muscle from the shells is believed to be caused by the denaturation of the muscle proteins and connective tissues to give a gelatin transition which results from the disruption of non-covalent interactions in the tertiary protein structures (Voisin, 2003; Cruz-Romero *et al.*, 2004). No additional mechanical force is necessary to facilitate complete adductor muscle release and oyster size is not a factor in the effectiveness of the process. The biggest drawback of this process is cost. High pressure processing vessels cost from \$750 000 to \$2 000 000 depending on capacity (Voisin, unpublished data). Many processors cannot afford this capital expenditure.

With the current, rapid advances in technology, modern oyster shucking processes have never been more efficient or more necessary. Oysters are not only appetizing to many but also are good and plentiful sources of protein, vitamins and minerals for people worldwide (Hedeen, 1986). The ability to

provide a safe, nutritious and renewable food product is not only important now, but may have significant implications for the future of sustainable agriculture. Recent technological advances have provided tremendous benefit to oyster processors, but more affordable methods still need to be identified and investigated (Cruz-Romero *et al.*, 2004). Oyster shucking methods in the future will need to have some distinct characteristics. First, the operation must be able to handle large volumes of oysters. This may be accomplished by either processing in large batches or by designing a continuous process. Next, the process will need to cause the release of the adductor muscle while maximizing yield. It must also be safe for operators of the machinery. In addition, the resulting product will need to be indistinguishable from raw oysters in taste, texture and appearance. A successful process for the half-shell market must also destroy pathogens inherent in raw oysters. Finally, the capital investment for the processing equipment must be kept to a minimum. Of the current processing technologies, the high pressure processes come closest to fulfilling all the requirements for a successful oyster shucking operation. One significant drawback of the high pressure processes is the capital investment. Other technologies that have not been fully investigated may offer an effective process at an affordable cost. One of the most promising technologies that have not been fully investigated is the use of lasers. In conjunction with some of the oyster positioning and imaging technologies (Chen & Wheaton, 1989; Li & Wheaton, 1992; So & Wheaton, 2002), this would allow the precise application of heat to the adductor muscle only. From personal, limited laboratory experimentation with precise application of heat to the shell immediately above the muscle scar, the result is a very clean release of the adductor muscle while maintaining a raw oyster. Other under-researched methods, such as chemical and electrical, are listed in Table 2. While much work has been done to date, there is still much to do to find an affordable and effective oyster shucking method.

Acknowledgments

The authors wish to acknowledge the faculty and staff of the Department of Biological and Agricultural Engineering of the LSU AgCenter.

Specific thanks for review and assistance are extended to Laura Gauthreaux, Dr Lynn Hannaman, Elizabeth Henkels, Dr Greg Lutz, Uma Nadimpalli, Dr Art Sterling and Dr John Supan. This publication has been approved by the LSU AgCenter as publication number 04-22-0144.

References

- Acton, R.T. (1970). *Immunobiological and Immunochemical Studies of the Oyster Crassostrea virginica*. Pp. ix, 134. New York: MSS Information Corporation.
- American Mussel Harvesters Inc. (2003). *Aphrodisiac Facts and Fictions*. Kingstown, Rhode Island: American Mussel Harvesters, Inc.
- Andrews, L.S., Park, D.L. & Chen, Y.P. (2000). Low temperature pasteurization to reduce the risk of vibrio infections from raw shell-stock oysters. *Food Additives and Contaminants*, **17**, 787–791.
- Anonymous (1993). *Vibrio vulnificus* infections associated with raw oyster consumption – Florida, 1981–1992. *Archives of Dermatology*, **129**, 957–958.
- Anonymous (2001). *The National Shellfish Sanitation Program – a Protocol for International Participation*. <http://www.cfsan.fda.gov/~ear/nsspprot.html>, U.S. Food and Drug Administration.
- Arthur, K.B. (1920). *Oyster-Shucking Knife*. United States Patent No. 1,352,108.
- Asklar, E.J. (1923). *Clam Opener*. United States Patent No. 1,465,799.
- Beecham, H.J. III, Oldfield, E.C. III, Lewis, D.E. & Buker, J.L. (1991). *Mycobacterium marinum* infection from shucking oysters. *The Lancet*, **337**, 1487.
- Berger, C.W. (1874). *Improvement in Oyster-Knives*. United States Patent No. 162,606.
- Blake, P. (1854). *Improved Oyster Knife*. United States Patent No. 10,798.
- Blangden, S. (1902). *Oyster-Opening Tool*. United States Patent No. 708,014.
- Boyer, M.C. (1871). *Improvement in Devices for Opening Oysters*. United States Patent No. 112,895.
- Brown, C.T. (1967). *Apparatus for Removing Scallops from Their Shells*. United States Patent No. 3,320,631.
- Brown, O. (1987). *Bivalve Mollusk Shucker*. United States Patent No. 4,691,412.
- Buras, N. (1919). *Hammer*. United States Patent No. 1,314,465.
- Carlson, L.H. (1907). *Clam and Oyster Opening Machine*. United States Patent No. 845,521.
- Carlson, H.C. (1979). *Mollusk Shucker*. United States Patent No. 4,141,114.
- Chen, Y.-P. (1996). *Reduction and Management of Vibrio vulnificus in Gulf Coast Oyster (Crassostrea virginica)*. Baton Rouge, LA, Louisiana State University: Dept. of Food Science, ix, 94 leaves.
- Chen, S.S. & Wheaton, F.W. (1989). Oyster hinge line detection using image-processing. *Aquacultural Engineering*, **8**, 307–327.
- Chin, K.P., Lowe, M.A., Tong, M.J. & Koehler, A.L. (1987). *Vibrio vulnificus* infection after raw oyster ingestion in a patient with liver disease and acquired immune deficiency syndrome-related complex. *Gastroenterology*, **92**, 796–799.
- Cleary, D.M. (1873). *Improvement in Devices for Opening Oysters*. United States Patent No. 144,063.
- Coccellato, M. (1969). *Clam Opening Device*. United States Patent No. 3,440,684.
- Cohen, M. (1980). *Process for Shucking a Mollusk*. United States Patent No. 4,198,728.
- Cohen, M. (1982). *Process for Shucking a Mollusk*. United States Patent No. 4,312,099.
- Colangelo, V.A. (1958). *Shell Fish Opener*. United States Patent No. 2,854,688.
- Colford, E.M. (1906). *Oyster-Opener*. United States Patent No. 829,693.
- Cook, W.H. (1937). *Steam Box*. United States Patent No. 2,102,943.
- Cook, D.W. (1997). Refrigeration of oyster shellstock: conditions which minimize the outgrowth of *Vibrio vulnificus*. *Journal of Food Protection*, **60**, 349–352.
- Cook, D.W. & Ruple, A.D. (1992). Cold storage and mild heat treatment as processing aids to reduce the numbers of *Vibrio vulnificus* in raw oysters. *Journal of Food Protection*, **55**, 985–989.
- Cook, D.W., O'Leary, P., Hunsucker, J.C. et al. (2002). *Vibrio vulnificus* and *Vibrio parahaemolyticus* in US retail shell oysters: a national survey from June 1998 to July 1999. *Journal of Food Protection*, **65**, 79–87.
- Cooley, R.H. & Bishop, H.W. (1902). *Oyster-Shucking or Oyster-Opening Knife*. United States Patent No. 715,988.
- Cox, J.P. (1979). *Oyster Processing Apparatus*. United States Patent No. 4,143,444.
- Cox, J.P. (1981). *Oyster Processing Method*. United States Patent No. 4,304,029.
- Cruz-Romero, M., Smiddy, M., Hill, C., Kerry, J.P., & Kelly, A.L. (2004). Effects of high pressure treatment on physiochemical characteristics of fresh oysters (*Crassostrea gigas*). *Innovative Food Science and Emergent Technologies*, **5**, 161–169.
- Dandridge, E.P. (1914). *Oyster-Shucking Machine*. United States Patent No. 1,117,984.
- De Lamarre, C.B. (1888). *Oyster-Knife*. United States Patent No. 390,759.
- DePaola, A., Nordstrom, J.L., Dalsgaard, A. et al. (2003). Analysis of *Vibrio vulnificus* from market oysters and septicemia cases for virulence markers. *Applied and Environmental Microbiology*, **69**, 4006–4011.
- Dickerson, L.E. (1924). *Oyster-Punching Device*. United States Patent No. 1,510,313.
- Doiron, F.A. (1949). *Scallop Shucking Machine*. United States Patent No. 2,476,962.
- Doxsee, J.H. & Cook, W.H. (1935). *Apparatus for Shelling Mollusks*. United States Patent No. 2,008,820.
- Doxsee, J.H.J. & Cook, W.H. (1937). *Method of Shelling Mollusks*. United States Patent No. 2,102,945.
- Earnshaw, D.C. (2000). *Shellfish Processing Apparatus*. United States Patent No. 6,110,032.

- Egli, H. (1923). *Oyster-Shucking Machine*. United States Patent No. 1,445,672.
- Eyton, T.C. (1858). *A History of the Oyster and the Oyster Fisheries*. London: John Van Voorst.
- Farrell, A.F. (1889). *Implement for Opening Oysters or Clams*. United States Patent No. 411,797.
- Ford, M.L. (1990). *The Incidence of Vibrio Species in Louisiana and Maryland Oysters (Crassostrea virginica)*. Dissertation, Louisiana State University, Baton Rouge. xi, 115 pages.
- Frazier, W.G. (1938). *Clam Opener*. United States Patent No. 2,136,816.
- Froome, B.E. (1986). *Portable Backyard Crab Cooker or Steamer*. United States Patent No. 4,616,625.
- Garcia, N.J. (1980). *The Presence of Vibrio parahaemolyticus in Oysters Along the Louisiana Gulf Coast*. Baton Rouge, LA, Louisiana State University: Dept. of Food Science, vii, 58 leaves
- Geldermans, J.E. & de Hond, A. (1943). *Process of Separating Shells and Meats of Bivalve Shellfish*. United States Patent No. 2,337,188.
- Gifford, W.J. (1990). *Water Cooled Roller Shucker for Shellfish*. United States Patent No. 4,924,555.
- Griffis, E.E. (1991). *Method and Apparatus for Eviscerating Scallops*. United States Patent No. 5,005,258.
- Groubert, T.N. & Oliver, J.D. (1994). Interaction of *Vibrio vulnificus* and the eastern oyster, *Crassostrea virginica*. *Journal of Food Protection*, **57**, 224–228.
- Hallock, V.R. (1935). *Clam-Opener*. United States Patent No. 2,000,075.
- Harris, S.G. (1952). *Method for Recovering Oysters*. United States Patent No. 2,608,716.
- Harris, S.G. (1953). *Apparatus for Recovering Oysters*. United States Patent No. 2,652,588.
- Harris, S.G. (1958). *Method of Recovering Meats of Bivalves*. United States Patent No. 2,822,989.
- Harris, S.G. (1960). *Apparatus for Recovering Meat from Bony Material by Flotation*. United States Patent No. 2,929,502.
- Harris, H. & Smith, D.A. (1985). *Methods and Apparatus for Thermal Blast Feeling, Skimming, or Shelling of Food Products*. United States Patent No. 4,524,681.
- Hartleb, B.B. & Hartleb, R.C. (1917). *Oyster-Opener*. United States Patent No. 1,232,682.
- Hawkins, J.N. (1862). *Improved Clam-Opener*. United States Patent No. 34,495.
- Hedeen, R.A. (1986). *The Oyster: The Life and Lore of the Celebrated Bivalve*. Centreville, MD: Tidewater Publishers.
- Heimlich, P. (1878). *Improvement in Oyster-Openers*. United States Patent No. 210,032.
- Helmer, G.W. (1970). *Clam Opener Device*. United States Patent No. 3,548,450.
- Hlady, W.G. (1997). *Vibrio infections associated with raw oyster consumption in Florida, 1981–1994*. *Journal of Food Protection*, **60**, 353–357.
- Hlady, W.G. & Klontz, K.C. (1996). The epidemiology of vibrio infections in Florida, 1981–1993. *Journal of Infectious Diseases*, **173**, 1176–1183.
- Holtzmann, G. (1871). *Improvement in Oyster-Shuckers*. United States Patent No. 115,474.
- Huffnagle, G.W. (1868). *Improvement in Oyster Knife*. United States Patent No. 75,917.
- Huppmann, J.P. (1889). *Oyster-Opener*. United States Patent No. 411,381.
- Jackson, J.K., Murphree, R.L. & Tamplin, M.L. (1997). Evidence that mortality from *Vibrio vulnificus* infection results from single strains among heterogeneous populations in shellfish. *Journal of Clinical Microbiology*, **35**, 2098–2101.
- Jenkins, M.B. (1936). *Method of Processing Edible Bivalves*. United States Patent No. 2,047,688.
- Keithly, W.R. & Diop, H. (2001). The impact of risk information on the demand for Gulf of Mexico and Chesapeake oysters. *Journal of Shellfish Research*, **20**, 1285–1291.
- Kennedy, V.S., Newell, R.I.E. & Eble, A.F. (1996). *The Eastern Oyster: Crassostrea virginica*. College Park: Maryland Sea Grant College.
- Kiczek, E.F. (1991a). *Method and Apparatus for Opening a Mollusk*. United States Patent No. 5,059,151.
- Kiczek, E.F. (1991b). *Method for Opening a Mollusk*. United States Patent No. 4,992,289.
- Klontz, K.C., Williams, L., Baldy, L.M. & Campos, M. (1993). Raw oyster-associated vibrio infections – linking epidemiologic data with laboratory testing of oysters obtained from a retail outlet. *Journal of Food Protection*, **56**, 977–979.
- Lapeyre, F.S., Lapeyre, J.M., Demarest, L.E. & Couret, R.F. (1961). *Process for the Recovery of Oyster Meats*. United States Patent No. 3,007,801.
- Lapeyre, F.S., Lapeyre, J.M., Demarest, L.R.E. & Couret, R.F. (1962). *Machine for Shucking Oysters*. United States Patent No. 3,037,237.
- Larsen, L., Larring, P. & Spink, R. (1957). *Land of the Tollund Man; the Prehistory and Archaeology of Denmark*. London: Lutterworth Press.
- Leduc, C. (1885). *Oyster-Opening Machine*. United States Patent No. 332,403.
- Lee, C.Y., Panicker, G. & Bej, A.K. (2003). Detection of pathogenic bacteria in shellfish using multiplex PCR followed by covalink (Tm) Nh microwell plate sandwich hybridization. *Journal of Microbiological Methods*, **53**, 199–209.
- Lefkowitz, A., Fout, G.S., Losonsky, G., Wasserman, S.S., Israel, E. & Morris, J.G. (1992). A serosurvey of pathogens associated with shellfish – prevalence of antibodies to *Vibrio* species and norwalk virus in the Chesapeake Bay Region. *American Journal of Epidemiology*, **135**, 369–380.
- Li, J. & Wheaton, F.W. (1992). Image processing and pattern recognition for oyster hinge line detection. *Aquacultural Engineering*, **11**, 231–250.
- Lofland, P.C. (1923). *Oyster Opener*. United States Patent No. 1,472,179.
- Lorca, T.A., Pierson, M.D., Flick, G.J. & Hackney, C.R. (2001). Levels of *Vibrio vulnificus* and organoleptic quality of raw shellstock oysters (*Crassostrea virginica*)

- maintained at different storage temperatures. *Journal of Food Protection*, **64**, 1716–1721.
- Lum, G.E. & Sanford, P.T. (1876). *Improvement in Oyster-Openers*. United States Patent No. 177,138.
- Martin, R.C. (1976). *Method for Shucking Shellfish*. United States Patent No. 3,988,805.
- Martin, R.C. (1982). *Shellfish Meat and Shell Separation Process and Apparatus*. United States Patent No. 4,309,793.
- Martin, D. (2004). *Optimization and Automation of a Thermal Oyster Shucking Process*. LSUPLD Dissertation, published by UMI Company, Ann Arbor.
- Marvin, J. & Henderson, T. Jr (1966). *Apparatus for Recovering Flesh from Bivalve Mollusks*. United States Patent No. 3,230,578.
- Megee, R.F. (1874). *Improvement in Combined Oyster Knives and Nippers*. United States Patent No. 159,598.
- Meyer, L. (1969). *Means for Processing Scallops for the Market*. United States Patent No. 3,465,382.
- Mostowicz, W. (1952). *Device for Splitting Clams*. United States Patent No. 2,609,565.
- Murphy, S.K. & Oliver, J.D. (1992). Effects of temperature abuse on survival of *Vibrio vulnificus* in oysters. *Applied and Environmental Microbiology*, **58**, 2771–2775.
- Namba, K., Kobayashi, M. et al. (1995). Persistent relaxation of the adductor muscle of oyster *Crassostrea gigas* induced by magnesium-ion. *Fisheries Science*, **61**, 241–244.
- Nelson, R.W., Mackin, R.F. & Tretsven, W.I. (1971). *Method for Shucking and Eviscerating Bivalve Mollusks*. United States Patent No. 3,594,860.
- Nguyen, K.-L., LaRock, P.A. & La Peyre, J.F. (2001). *Vibrio vulnificus* infection of oyster cells: a possible survival mechanism. *Aquaculture 2001 Book of Abstracts*, 475.
- Palmere, F. (1957). *Oyster and Clam Opener*. United States Patent No. 2,808,613.
- Paparella, M.W. & Allen, M. (1970). Gaping oyster by shock wave energy. *Chesapeake Sci.*, **11**, 111.
- Pattberger, W. (1869). *Improvement in Combined Oyster-Knife and Ice-Pick*. United States Patent No. 98,102.
- Peixotto, S.S., Finne, G., Hanna, M.O. & Vanderzant, C. (1979). *Presence, Growth and Survival of Yersinia enterocolitica in Oyster, Shrimp and Crab, Texas A and M Univ., College Station*. Pp. 9. Rockville, MD: Dept. of Animal Science, Sponsor: National Oceanic and Atmospheric Administration, Office of Sea Grant. Dec 1979.
- Peoni, J. (1971). *Clam Opener*. United States Patent No. 3,583,026.
- Petersen, F.H. & Sorensen, K.A. (1992). *Procedure for Shelling of Crustaceous Shellfish, Especially Shrimps, and Apparatus for Performance of the Procedure*. United States Patent No. 5,112,269.
- Phillips, L.S. (1979). *Thermal Resistance of Vibrio parahaemolyticus in Gulf Oysters*. Baton Rouge, LA: Dept. of Food Science, Louisiana State University, viii, 49 leaves.
- Philpots, J.R. (1890). *Oysters, and All About Them: Being a Complete History of the Titular Subject, Exhaustive on All Points of Necessary and Curious Information from the Earliest Writers to Those of the Present Time, with Numerous Additions, Facts, and Notes*. London: J. Richardson.
- Polansky, I. (2003). *Oysters (Ostrea edulis and Others)*. *FoodTale: OYSTERS*. Montreal: Soupsong.com. 2003.
- Rand, J.A. (1906). *Oyster-Shucking Knife*. United States Patent No. 829,353.
- Rey, H.D. (1960). *Method of Opening Oysters*. United States Patent No. 2,942,292.
- Richens, J.M. (1926). *Oyster-Opening Device*. United States Patent No. 1,597,622.
- Roters, A.H. (1908). *Oyster-Opener*. United States Patent No. 896,162.
- Ruple, A.D. & Cook, D.W. (1992). *Vibrio vulnificus* and indicator bacteria in shellstock and commercially processed oysters from the gulf coast. *Journal of Food Protection*, **55**, 667–671.
- Schmidt, H.F. (1913). *Oyster-Opener*. United States Patent No. 1,071,352.
- Seal, R.D. & Harris, S.G. (1958). *Apparatus for Recovering the Meats of Bivalves*. United States Patent No. 2,823,414.
- Seipel, J. & Rupp, W. (1858). *Improvement in Oyster-Openers*. United States Patent No. 19,050.
- Shapiro, R.L., Altekruze, S., Hutwagner, L. et al. (1998). The role of gulf coast oysters harvested in warmer months in *Vibrio vulnificus* infections in the United States, 1988–1996. *Journal of Infectious Diseases*, **178**, 752–759.
- Singh, G. (1972). Laser modernizes oyster shucking. *Food Technology*, **26**, 60–61.
- Skrmetta, R.Q. (1958). *Oyster Shucking Machine*. United States Patent No. 2,818,598.
- Snow, H.F. (1971a). *Shucking of Bivalves*. United States Patent No. 3,564,648.
- Snow, H.F. (1971b). *Shucking of Bivalves*. United States Patent No. 3,566,438.
- So, J.D. & Wheaton, F.W. (2002). Detection of *Crassostrea virginica* hinge lines with machine vision software development. *Aquacultural Engineering*, **26**, 171–190.
- Sobsey, M.D., Hackney, C.R., Carrick, R.J., Ray, B. & Speck, M.L. (1980). *Occurrence of Enteric Bacteria and Viruses in Oysters, North Carolina Univ. at Chapel Hill*. Pp. 5. Rockville, MD: National Oceanic and Atmospheric Administration, Office of Sea Grant.
- Spracklin, B.W. (1971). *Microwave Process for Shucking Bivalve Mollusks*. United States Patent No. 3,585,676.
- Starin, J. & John, H. (1872). *Improvement in Oyster-Openers*. United States Patent No. 133,267.
- Stewart, W.F. (1889). *Oyster-Opener*. United States Patent No. 402,867.
- Stott, R. (2003). *The Secret Life of Oysters*. Independent Digital. London.
- Sun, Y. & Oliver, J.D. (1995). Hot sauce – no elimination of *Vibrio vulnificus* in oysters. *Journal of Food Protection*, **58**, 441–442.
- Svec, F.A. (1950). *Device for Use in Opening Bivalve Mollusks*. United States Patent No. 2,506,817.
- Tamplin, M.L. & Capers, G.M. (1992). Persistence of *Vibrio vulnificus* in tissues of gulf coast oysters, *Crassostrea virginica*, exposed to seawater disinfected with UV-light. *Applied and Environmental Microbiology*, **58**, 1506–1510.

- Taylor, L.S. (1983). *Method for Shucking Bivalve Mollusks Using Microwave Energy*. United States Patent No. 4,420,492.
- Telford, F.M. (1995). *Nipper Tool to Aid Oyster Shucking*. United States Patent No. 5,399,117.
- Temple, T.W. (1877). *Improvement in Implements for Opening Oysters*. United States Patent No. 191,384.
- Thompson, G.W. (1889). *Oyster-Opening Implement*. United States Patent No. 408,939.
- Thompson, G. (1956). *Clam Opener*. United States Patent No. 2,747,220.
- Thompson, J.W. (1976). *Oyster Breaker Operated by Electric Motor Having Bearing Seal Device*. United States Patent No. 3,934,311.
- Tiffany, E.D. (1912). *Clam-Opener*. United States Patent No. 1,041,198.
- Torsch, E.L. & Parker, J.H. (1907). *Machine for Shucking Oysters*. United States Patent No. 848,784.
- Towers, W.H. (1854). *Improved Machine for Opening Oysters*. United States Patent No. 10,810.
- Twuyver, R.V. & Johnson, J.M. (1980). *Bivalve Mollusk Shucking Apparatus and Method*. United States Patent No. 4,236,276.
- Voisin, E.A. (2003). *Process of Elimination of Bacteria in Shellfish and of Shucking Shellfish*. United States Patent No. 6,537,601.
- Wells, R. (1879). *Improvement in Oyster-Shucking Machines*. United States Patent No. 211,449.
- Wenstrom, R.T. & Gorton, T.S. (1970). *Method of Shucking Shellfish*. United States Patent No. 3,528,124.
- Wenstrom, R.T. & Gorton, T.S. (1985). *Apparatus for Opening and Eviscerating Scallops*. United States Patent No. 4,532,677.
- Wheaton, F.W. (1971). Pp. 157. *Oyster Processing Study, Maryland Univ., College Park. Dept. of Agricultural Engineering*. Washington, D.C.: National Marine Fisheries Service, Maryland Dept. of Natural Resources, Annapolis.
- Wood, J.S. (1892). *Oyster-Knife*. United States Patent No. 469,312.
- Zimmers, A.M. (1911). *Oyster-Punching Machine*. United States Patent No. 1,007,411.
- Zucchini, F. (1895). *Oyster-Opening Machine*. United States Patent No. 545,329.