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Optimization and automation of a thermal oyster shucking process

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OPTIMIZATION AND AUTOMATION OF A THERMAL OYSTER SHUCKING PROCESS

A Dissertation

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by
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Abstract

Louisiana Gulf Coast oysters (*Crassostrea virginica*) were subjected to thermal shucking treatments to effect adductor muscle release from both left and right valves. The oysters were instrumented with thermocouples to monitor and record process temperatures in the oysters and on the shell. Following treatment, the oysters were evaluated for relaxation and release of the adductor muscle, meat quality and texture, and for the effect of the treatments on the storage life of the oysters as measured by total microbial plate counts. The treatments of many oysters resulted in a complete release of the adductor muscle from the shell while maintaining a quality raw product. One of the most promising treatments was a 60 second steam injection followed by a 60 second hold time and 120 seconds of ice water bath. This treatment proved exceptional overall with shelf stability over 14 days, an overall Average Release Value of 1.18 and an overall Quality of 1.86, both of which are good. A second treatment consisting of a 15 second pre-heat followed by a 45 second steam injection, no hold time and 4 minutes of ice water bath resulted in an overall Average Release Value of 0.33, which is excellent, and an overall Quality of 2.10 which is very close to acceptable. Sixty-seven percent of the oysters subjected to this treatment were considered successfully shucked based on degree of release and quality. Processing did affect the texture of the oysters but seemed to have little overall effect on storage life. This low-pressure steam process shows promise as an effective, low-cost alternative to current, high pressure commercial oyster shucking processes.

Chapter 1. Introduction

Oysters (*Crassostrea virginica*) are one of the most economically important seafoods harvested in Louisiana. In 2001, Louisiana oystermen harvested 13.2 million pounds of oyster meat, accounting for about 37% of the 2001 United States oyster production of 35.4 million pounds (Meyers, 2001). In Louisiana, oysters as an aquaculture industry have the third highest gross farm value of $20.7 million, next only to catfish at $39.8 million and crawfish at $36.9 million (Lutz, 2001). When value added processing is figured in, the actual economic value to the state approximates $34 million. And it's an industry on the rise. Over the last forty years, oyster leases have increased from 73,591 acres in 1960 to 409,209 acres in 2003 (Meyers, 2003).

Although the supply of oysters in Louisiana is plentiful, two major obstacles plague the industry. A large percentage of the state's oysters are manually shucked. Increasing labor costs and a severe shortage of skilled shuckers has adversely affected the industry. In addition, health concerns over the consumption of raw oysters by individuals with compromised immune systems resulting in sickness and death has negatively impacted the industry's profit (Keithly et al., 2001).

In an effort to address these two issues, a thermal (steam-based) oyster shucking process was investigated to evaluate its ability to effectively shuck oysters while maintaining a raw product. In addition, the effect of the shucking process on the oyster microbial flora will be evaluated to determine if any of the treatments were effective at reducing bacterial counts.

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Chapter 2. 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 5,000 years before Christ (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 over 2,000 years ago (Eyton, 1858). Oysters were the white truffles of royalty and emperors. 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 sapid 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 (Figure 1).

Oysters are composed of two calcareous valves or shells wherein the soft body of the oyster lies (Figure 2). 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

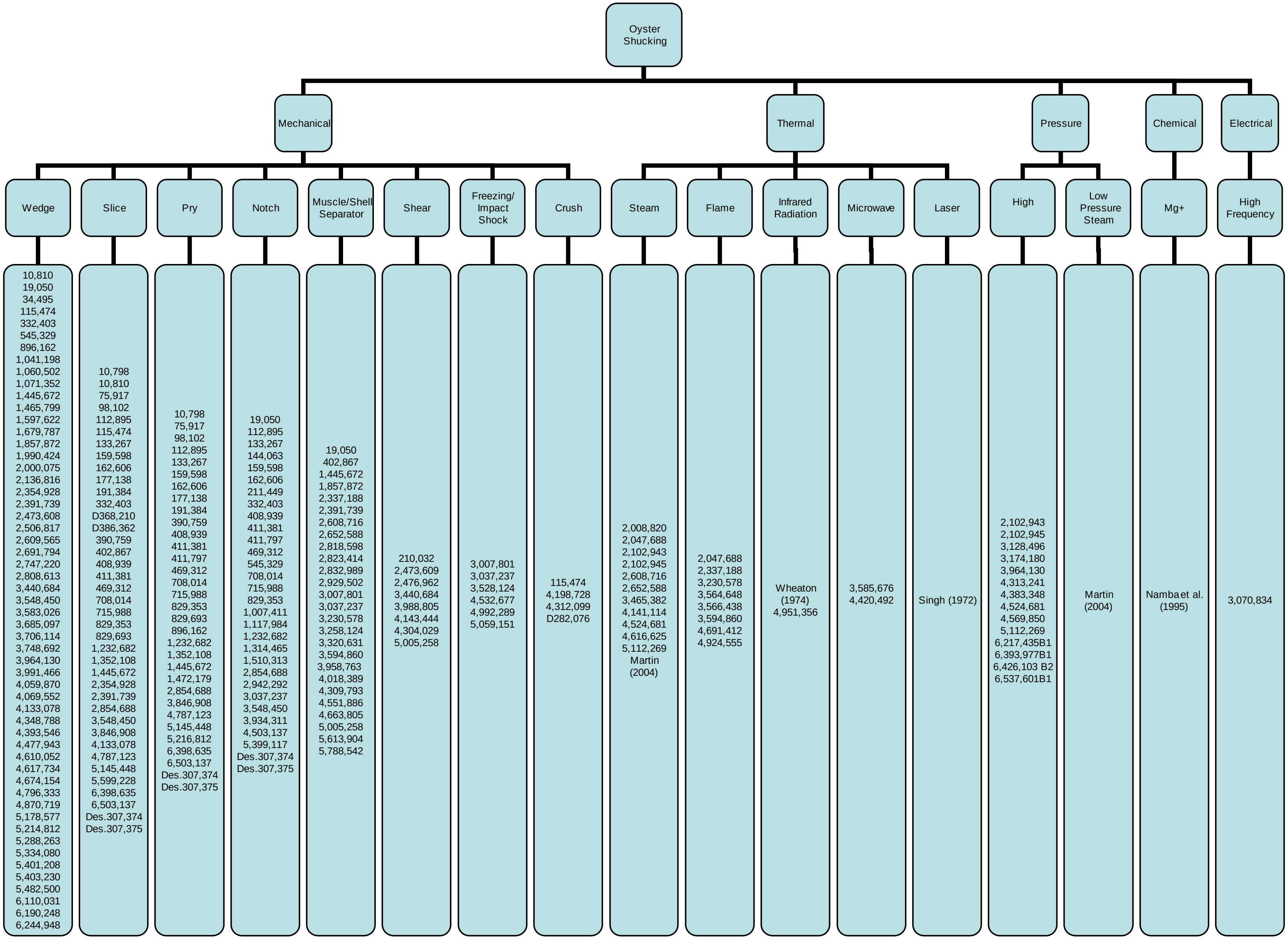

Figure 1. A summary of United States oyster shucking patents and research (Source: U.S. Patent and Trademark Office).

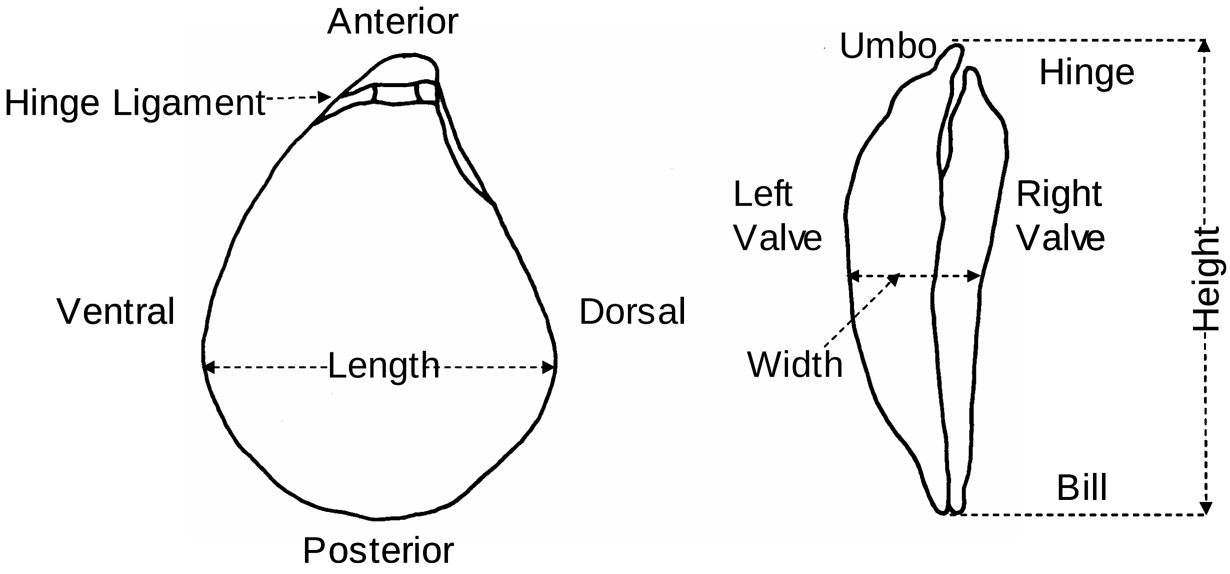

Figure 2. Diagram depicting anatomical features and the height, width and length of an oyster.

counteracts the force of the adductor muscle which closes the valves. The ligament goes into tension when the 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 fibers and opaque in color 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). More recently in the mid-1800's, the oyster knife was invented along with its many variations and modifications (Blake, 1854; Huffnagle, 1868; Pattberger, 1869; Boyer, 1871; Starin, 1872; Berger, 1874; Megee, 1874; Lum et al., 1876; Temple, 1877; De Lamarre, 1888; Huppmann, 1889; Thompson, 1889; Wood, 1892; Blangden, 1902; Cooley et al., 1902; Colford, 1906; Rand, 1906; Hartleb et al., 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 at 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. Since there is no heat involved in the process, the final product also remains in a raw state. However, this method of shucking requires skilled labor 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 labor intensive and as labor costs increase and qualified shuckers become harder to find, profit margins may be reduced.

In the mid-1800's to mid-1900's, inventors, realizing how difficult manual shucking was, designed lever-operated oyster shucking devices to assist with this task. 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 et al., 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 et al., 1858; Boyer, 1871; Starin, 1872; Cleary, 1873; Berger, 1874; Megee, 1874; Wells, 1879; Leduc, 1885; Farrell, 1889; Huppmann, 1889; Thompson, 1889; Wood, 1892; Zucchini, 1895; Blangden, 1902; Cooley et al., 1902; Rand, 1906; Zimmers, 1911; Dandridge, 1914; Hartleb et al., 1917; Buras, 1919; Dickerson, 1924; Colangelo, 1958; Rey, 1960; Lapeyre et al., 1962; Helmer, 1970; Thompson, 1976; Telford, 1995).

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 and Parker, 1907). While these machines produced a mechanically shucked raw oyster, the main drawback from these machines is that yield likely suffered 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 et al., 1935; Jenkins, 1936; Cook, 1937; Doxsee et al., 1937; Geldermans et al., 1943; Doiron, 1949; Harris, 1952; Harris, 1953; Harris, 1958; Seal et al., 1958; Skrmetta, 1958; Harris, 1960; Lapeyre et al., 1961; Lapeyre et al., 1962; Marvin et al., 1966; Brown, 1967; Meyer, 1969; Wenstrom et al., 1970; Nelson et al., 1971;

Snow, 1971a; Snow, 1971b; Martin, 1976; Carlson, 1979; Cox, 1979; Cohen, 1980; Twuyver et al., 1980; Cox, 1981; Cohen, 1982; Martin, 1982; Wenstrom et al., 1985; Brown, 1987; Gifford, 1990; Griffis, 1991; Kiczek, 1991a; Kiczek, 1991b; Petersen et al., 1992; Earnshaw, 2000).

The first steaming operation for shucking oysters was recorded in 1935. Heat has long been known to relax the adductor muscle. Doxsee et al. (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 minutes 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 canning. Many other inventions followed that successfully utilized steam for shucking oysters (Jenkins, 1936; Cook, 1937; Doxsee et al., 1937; Harris, 1952; Harris, 1953; Meyer, 1969; Carlson, 1979; Harris et al., 1985; Froome, 1986; Petersen et al., 1992). Although most all of these were used for canning operations where cooking of the oysters was acceptable, one steaming operation for shucking scallops claimed to produce a “fresh” product (Meyer, 1969). He proposed 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 separates the meat from the shells.

Other heating methods also were 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 time treatment resulted in an uncooked shucked mollusk. 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 1960's came the opportunity to investigate the practicality of applying this technology to oyster shucking. Spracklin (1971) found that controlled exposure of bivalve mollusks 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 *enmasse* 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 1960's and early 70's. Gaping of oyster shells by high-intensity shock waves was tried by Paparella and 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 connecting 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 seconds. Current higher power lasers could reduce that time substantially and may be more economically feasible now than the lasers used for the study.

Since the 1970's, 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; Cook et al., 1992; Lefkowitz et al., 1992; Murphy et al., 1992; Ruple et al., 1992; Tamplin et al., 1992; [Anon], 1993; Klontz et al., 1993; Groubert et al., 1994; Sun et al., 1995; Chen, 1996; Hlady et al., 1996; Cook, 1997; Hlady, 1997; Jackson et al., 1997; Shapiro et al., 1998; Andrews et al., 2000; Keithly et al., 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 favor their growth. As a filter feeder, oysters ingest and retain these bacteria. Most people are unaffected by consumption of raw oysters when 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.

While many of the shucking methods to this point 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, 2003b). The process calls for 10,000 to 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 pre-determined isostatic pressure for 1 to 15 minutes 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. 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 a gelatin transition which results from the disruption of non-covalent interactions in tertiary protein structures (Voisin, 2003b). 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 the cost. High pressure processing vessels run from $750,000 to $2,000,000 depending on the capacity (Voisin, 2003a). 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 peoples in the U.S. and abroad (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. 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 also must 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 also must 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 the closest to fulfilling all the requirements for a successful oyster shucking operation. The only real drawback from 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. In my opinion, one of the most promising technologies that has not been fully investigated is the use of lasers. In conjunction with some of the oyster positioning technologies (Chen et al., 1989), 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 Figure 1. While much work has been done to date, there is still much to do to find an affordable and effective oyster shucking method.

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Chapter 3. Development and Testing of a Heat-Cool Methodology to Automate Oyster Shucking

Introduction

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 5,000 years before Christ (Larsen et al., 1957). The Romans, however, are most noted for their love of oysters over 2,000 years ago (Eyton, 1858). Although prized for their taste, oysters were difficult to open. The challenge thus posed, the quest has been on to design a better way to shuck an oyster.

Oyster Biology and Physiology

Some basic oyster biology and physiology can be useful in understanding this challenge. Oysters are composed of two calcareous valves or shells wherein the soft body of the oyster lies (Figure 3). 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 opens and closes the valves. The ligament goes into tension when the oyster is closed and into compression when the oyster is in the relaxed state and open.

The adductor muscle is composed of two different muscle types (Figure 4). The majority of the adductor muscle is translucent and obliquely striated (2). This muscle is fast-acting and provides protection for the oyster and helps expel pseudofaecal material from the mantel with a rapid closing motion. 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 (1) with smooth muscle fibers and opaque in color 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.

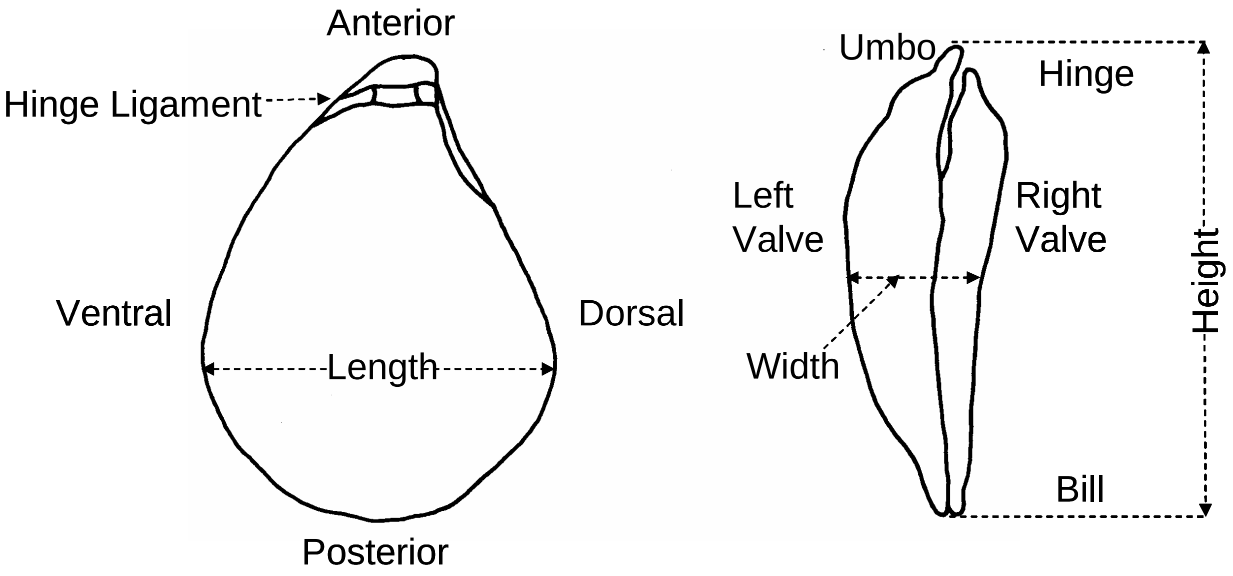

Figure 3. Diagram depicting anatomical features and the height, width and length of an oyster.

Oyster Shucking Methods

Shucking an oyster involves not only separating the valves of the oyster but also severing or causing a release of the adductor muscle from the shell. 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). More recently in the mid 1800's, the oyster knife was invented

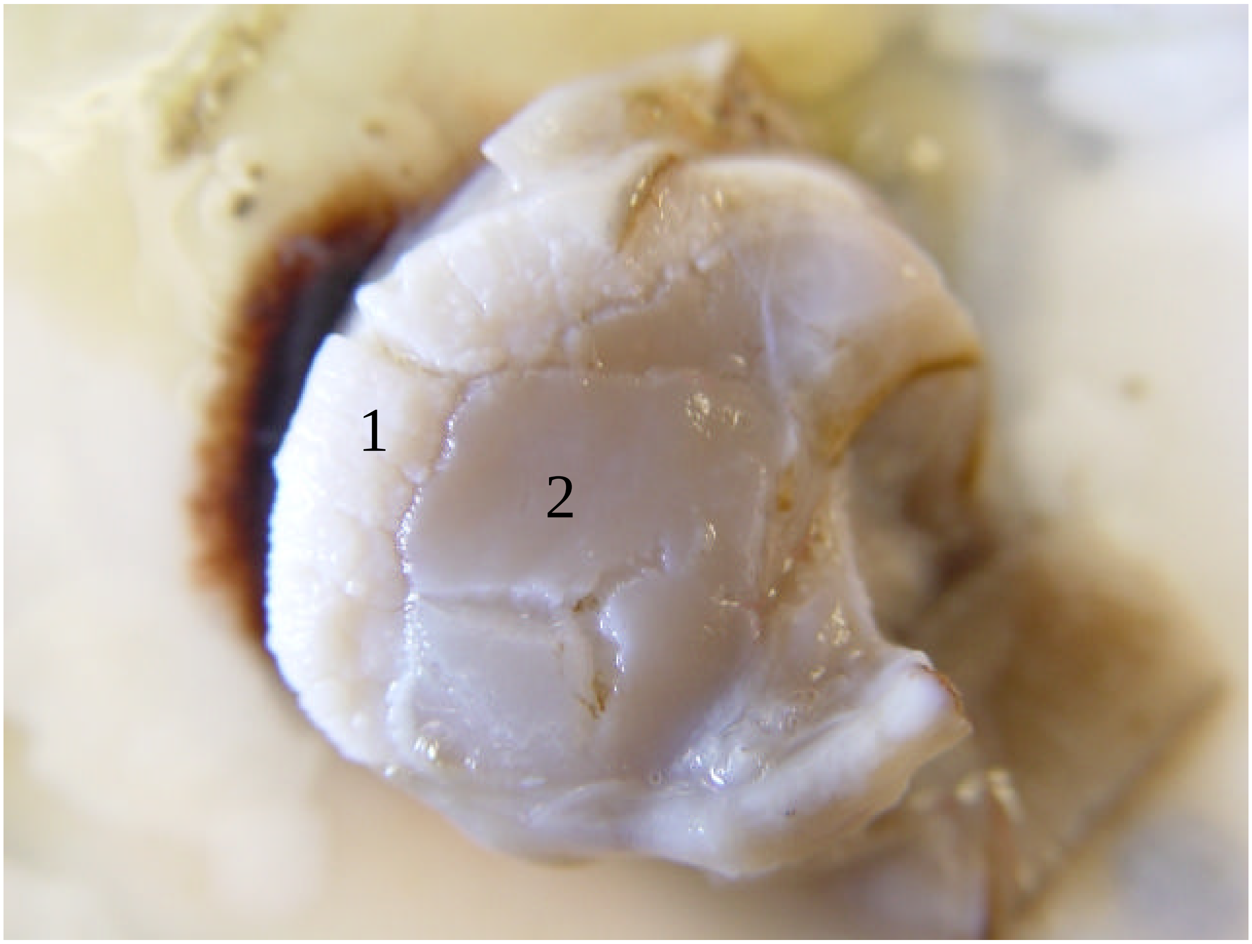

Figure 4. Oyster adductor muscle showing two distinct muscle types. 1) Slow acting, strong hold, opaque muscle and, 2) Fast acting, translucent muscle.

along with its many variations and modifications (Blake, 1854; Huffnagle, 1868; Pattberger, 1869; Berger, 1874; Megee, 1874; De Lamarre, 1888). This is still the standard today as it allows for inexpensive albeit challenging access to the oyster. It is good at 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. Since there is no heat involved in the process, the final product also remains in a raw state. However, this method of shucking requires skilled labor so that the oyster is not cut as the muscle is severed. Failure to exercise caution when severing the adductor muscle will result in yield loss as the oyster is cut and "bleeds." In addition, shucking by knife is labor intensive and as the number of skilled shuckers decreases, labor costs increase, thus reducing profit margins. More recent oyster shucking processes have utilized lasers (Singh, 1972), microwave energy (Spracklin, 1971), radiant heating and freezing (Wheaton, 1971), and high pressure (He et al., 2002; Voisin, 2002; Voisin, 2003). Of these, only high pressure processing is used to any degree commercially but is an expensive process.

Objectives

The goal of this project was to evaluate a freeze-heat-cool process to facilitate oyster shucking via shell gaping and raw-like meat detachment. A central challenge was investigating the heat transfer properties of live oysters. The instrumentation techniques pioneered here have provided some important data, as well as novel techniques applicable in a variety of situations. Microbial shelf-life was investigated and compression analysis was performed to compare textures between treated and untreated oysters, yielding quantitative, repeatable data on how the consumer acceptability of treated oysters might be impacted. Specific study objectives were as follows:

A. To develop instrumentation techniques for understanding the underlying transport phenomena and measuring heating and cooling dynamics in live oysters;

B. To design and develop the equipment setups needed for testing heating via steam and cooling via carbon dioxide, nitrogen and ice water in a cooling apparatus;

C. To quantify oyster meat detachment and correlate with estimated and/or measured heating and cooling phenomena;

D. To determine treatment effects on microbes as measured by total plate counts and shelf-life of treated oysters stored at 2^{o}C over a two week period; and

E. To develop a method of measuring texture changes in oysters after treatment via use of a Vitrodyne compression testing apparatus.

Oyster Procurement

Oysters (*Crassostrea virginica*) were obtained from Bradford Seafood Co. of Pass Christian, Mississippi. Oysters also were procured from the LSU Oyster Hatchery at Grand Isle, Louisiana, which had a different growing environment. The oysters were kept cool on ice during transport and held under refrigeration (2ºC) prior to treatment. New batches of oysters typically were obtained every 7 days. Oysters more than 14 days old were not used in the research.

Dual Methodologies

Two different methodologies were employed to conduct the research. Method 1 utilized dedicated, hard-plumbed steam at a constant 30 psi, manually operated ball valves in each of the lines, and a Campbell Scientific 23X datalogger. Under Method 1, the vacuum pump was able to draw a maximum vacuum of close to 1 atmosphere (-14.7 psi) whereas in Method 2, the maximum achievable vacuum was -8.5 psi. In addition, pre-freezing and rapid post-process cooling with nitrogen and CO_2 also was pursued under Method 1, but not with Method 2. A steam generator provided steam for Method 2 at pressures ranging from 30-55 psi, but at a lower volumetric flow rate than in Method 1. Solenoid valves also were installed on the steam supply line, vacuum line and vent line for Method 2, replacing the manually operated ball valves. A Campbell Scientific CR7 datalogger was used to record time and temperature data for Method 2.

Oyster Instrumentation

In order to measure retort and oyster temperature, T-type thermocouples were placed internally to document meat and shell temperature. Selected oysters were instrumented with three thermocouples at positions outside the shell, inside the shell, and inside the center of the oyster to measure the temperature profile dynamics through the shell. Method 2 differed only in that the inside meat thermocouples were specifically placed in the adductor muscle. Two one-eighth inch holes were drilled in the left valve of the oyster. Both holes were drilled near the outer edge of the oyster, one being horizontal and the other vertical. These holes were then cleaned of any drilling debris and blotted dry of water and oyster liquor. In the horizontal hole, a T-type thermocouple was inserted near the center of the oyster's soft tissue near the adductor muscle. In the second hole, the thermocouple was inserted vertically downward through the right valve until it made contact with the inner shell on the left valve. This thermocouple was then slid about an inch along the inner surface of the shell. Both holes were then dried again and sealed with modeling clay (Figure 5). A third thermocouple was located external to the shell and all three were held in place by a rubber band located near the hinge (Figure 6). Some oysters also were banded posteriorly to prevent opening during the steaming operation.

Each batch consisted of five to eight oysters arranged in a single layer; three of these were instrumented. The oysters were placed in (Method 1) or on (Method 2) a mesh basket and lowered into the vessel. A portion of the vessel rim was lined with vinyl weather striping to maintain the pressure seal at the point where the thermocouples exited the vessel. Weather-stripping also was placed on top of the thermocouple wires before the lid was shut (Figure 7). The vessel was then closed.

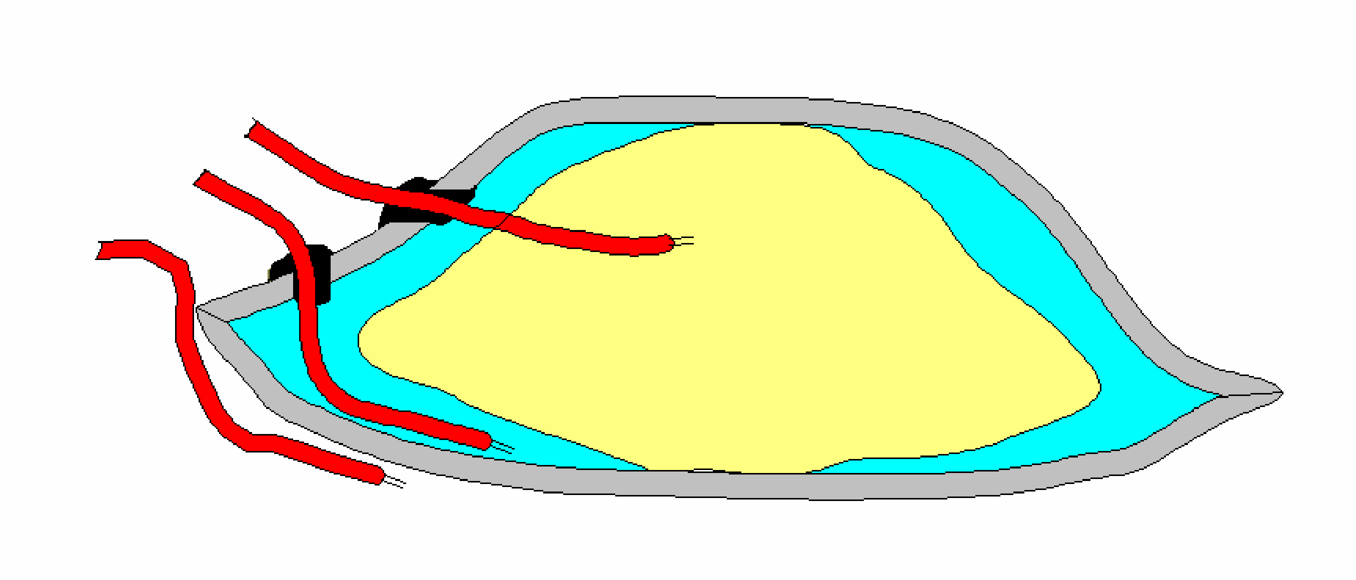

Figure 5. Thermocouple placement within and on an instrumented oyster.

Figure 6. Instrumented oyster with clay plugs.

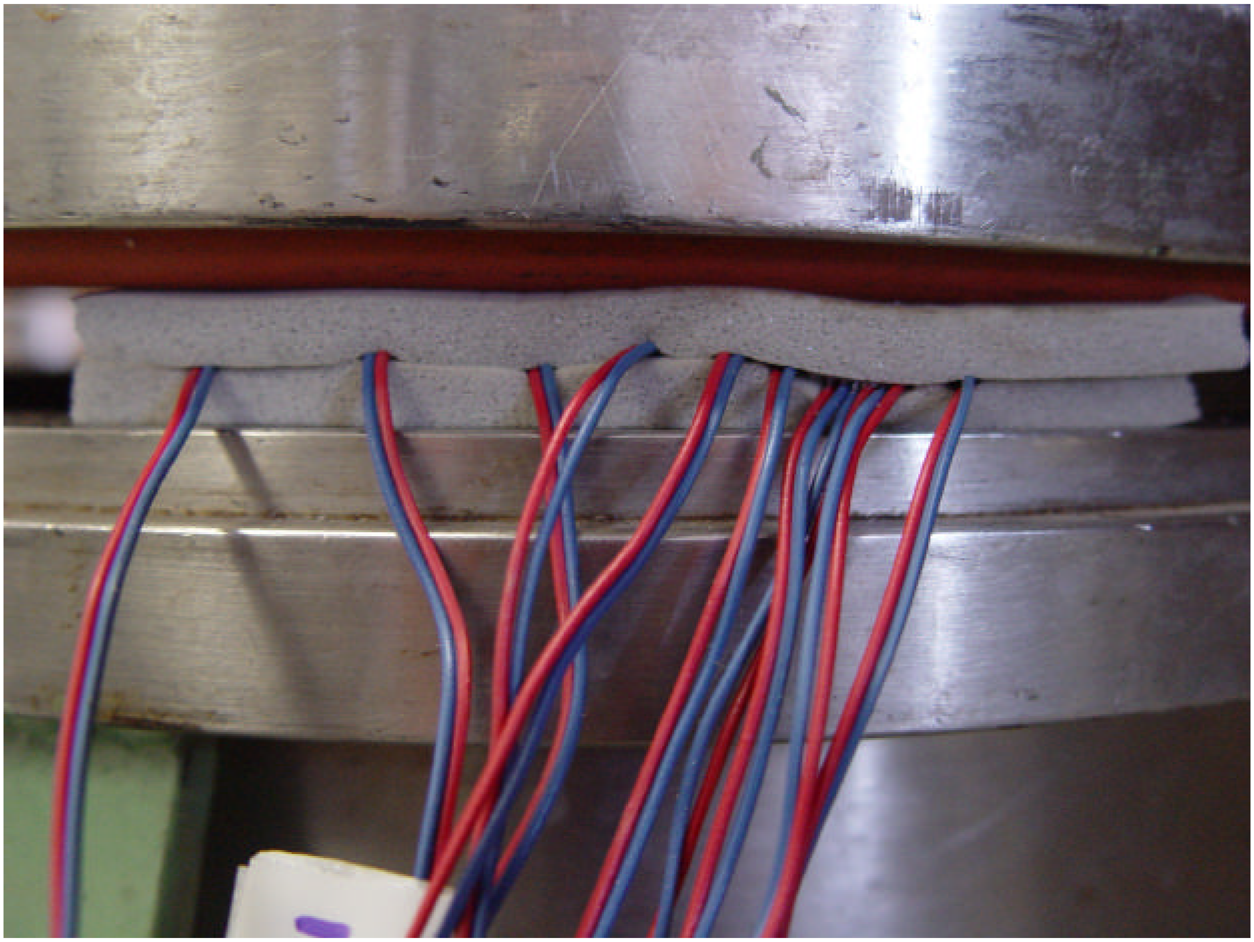

Figure 7. Application of weather-stripping to lip of retort to protect thermocouple wires.

Data Acquisition

A Campbell Scientific 23X (Method 1) and CR7 with 14 channel RTD (Method 2) datalogger (Campbell Scientific Incorporated, Logan, Utah) was used to collect and record the temperature outputs from the instrumented oysters (Figure 8). Data were collected every one-tenth of a second (1 Hz) on ten channels (Method 1) and every three-tenths of a second (Method 2) based on available datalogger memory allocation. As mentioned, each oyster was instrumented in three places and three oysters were instrumented per run. This used nine of the input channels and the tenth was used to record vessel temperature. A notebook computer was used to download temperature data from the datalogger after each run (Figure 9).

Pressure data also were collected using an electronic pressure transducer. A pressure meter (Extech Instruments Corp., Waltham, Maine) and its accompanying software monitored and recorded pressure data within the vessel at a frequency of 1 Hz.

System Setups

Research under Method 1 was conducted at the LSU Muscle Foods Laboratory using existing steam and cryogenic capabilities. Steam was supplied at 30 psi and applied under

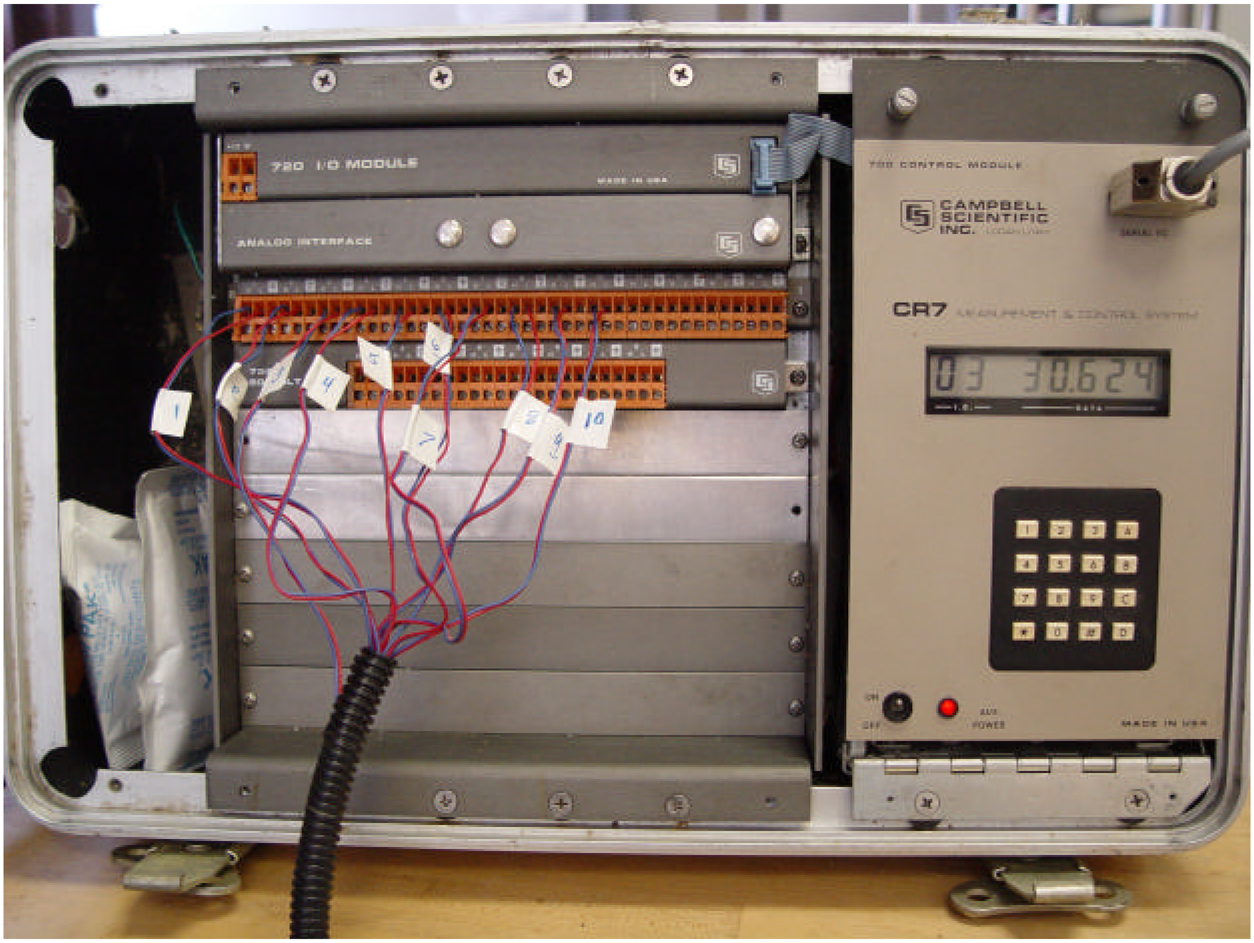

Figure 8. Campbell Scientific CR7 datalogger with attached T-type thermocouples.

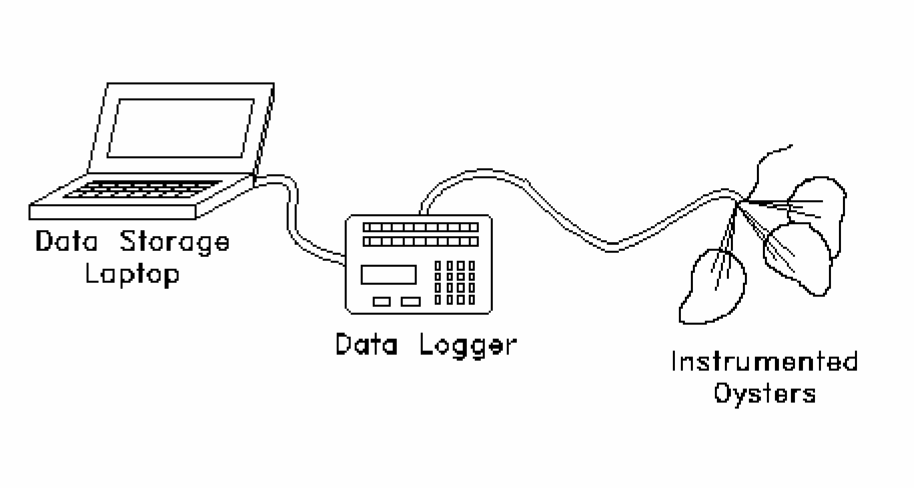

Figure 9. Data acquisition system for instrumenting oysters.

using a steam retort provided by Ing. Darecchio S.R.L., a manufacturer of processing equipment used to shuck cockles, clams, mussels and scallops in Europe. Research conducted under Method 2 was conducted in the Food Processing Lab at the Department of Biological and Agricultural Engineering at Louisiana State University.

Referring to the automated oyster shucking system overview (Figure 10), steam was supplied at 30 – 60 psi and applied under vacuum in the steel retort (6). The vessel had a steam supply line (4) and solenoid valve (Model M-1-3T, J.D. Gould Company, Indianapolis, Indiana) (5) for pressurized steam, a solenoid operated vent valve (8), and a manually operated drain valve (7) to remove condensed water in the bottom of the retort. An o-ring on the lid (15) provided a pressure tight seal. Oysters were placed inside the retort on the top of an inverted stainless steel mesh basket (Figure 11). The inversion of the basket for Method 2 allowed better distribution of the steam to the oysters.

Figure 10. Automated oyster shucking system overview.

Figure 11. A view inside the steel retort.

Under Method 2, steam was supplied by a steam generator (Model LB-25, Electro-Steam Generator Corp., Alexandria, Virginia) (Figure 12) and controlled by either a ball valve (Method 1) or by the solenoid valve (5) in the line (Method 2). A vacuum pump (Model RVA9, Robushi, Pompe, Italy) (1) was used to lower the pressure in the vessel to approximately –14 psi (Method 1) or -8.5 psi (Method 2) as measured by a pressure transducer and meter (10). A supply of water was required (14) for pump operation and was controlled by a ball valve at the base of the vacuum pump. A 210v electrical supply line (11) powered the pump and was controlled by a switch (2) mounted on the top of the pump's motor. The water used to create the vacuum for the pump was discharged through a drain pipe (12). Vacuum was drawn in the retort (6) by actuating the solenoid valve (3) leading to the vacuum pump. At the end of the runs, chilled ice water (13) was drawn in through rubber tubing by manually opening a ball valve (9) and turning on the vacuum pump. A schematic of the system is shown in Figure 13.

Up to eight oysters were used in each batch for various steam treatments. Oysters were subjected to a heat treatment and some were rapidly cooled upon removal. Methods for cooling were either submerging the oysters in an ice bath or placing in a cryogenic tunnel (Figure 14). The tunnel had the capability to use either nitrogen or carbon dioxide for differing degrees of chilling. This was done to minimize the cooking effect of steam after treatment and to test the effectiveness of pre-freezing prior to treatment.

Experimental Design

Initially, treatments were laid out in a randomized block design, varying the pre-freeze, pre-heat, steam injection and hold time in neat, orderly increments, but it became readily apparent that many of the treatment combinations were either not effective or ended up cooking

Figure 12. Steam generator.

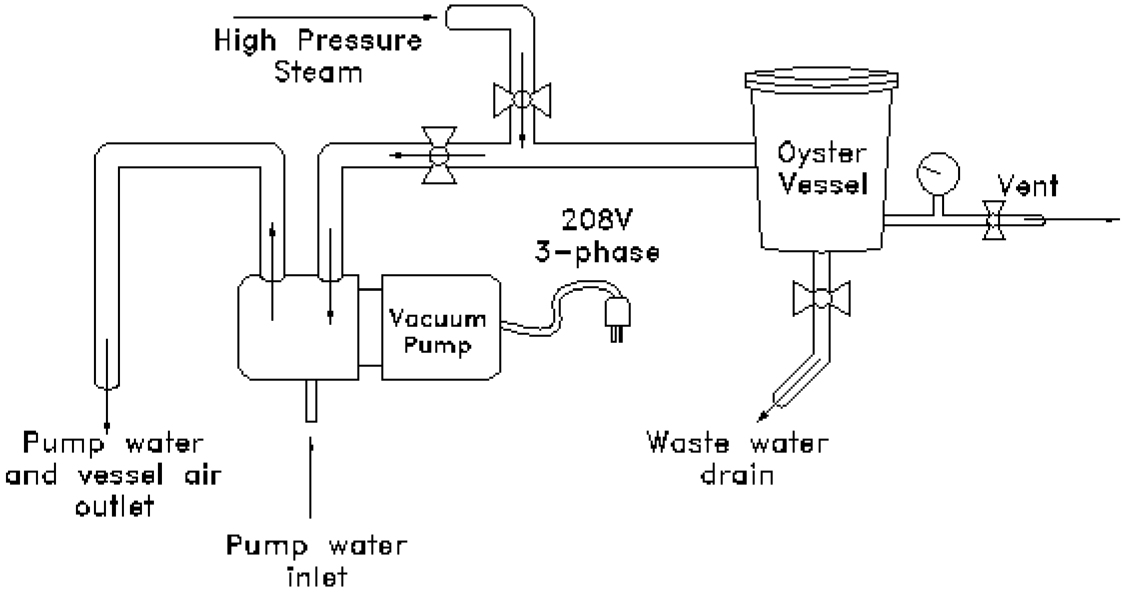

Figure 13. Automated oyster shucking system schematic.

the oysters. The approach was revised to focus in on promising treatment combinations. One of the factors taken into account when determining treatments was the origin of the oysters, as it influenced shell density and thickness. Oysters from Louisiana did not respond to heat treatments in the same way as the oysters from Mississippi did. This is most likely due to the two shell types that resulted from the different environments in which the oysters were grown. The oysters from Mississippi had a flakier, less dense shell structure. As a result, modified heat treatments were used for these oysters. This included preheating the oysters in the retort with steam prior to pulling a vacuum. A comprehensive list of treatments is listed in Table 1 and Table 2. These lists represent the various treatment combinations for the 697 oysters tested.

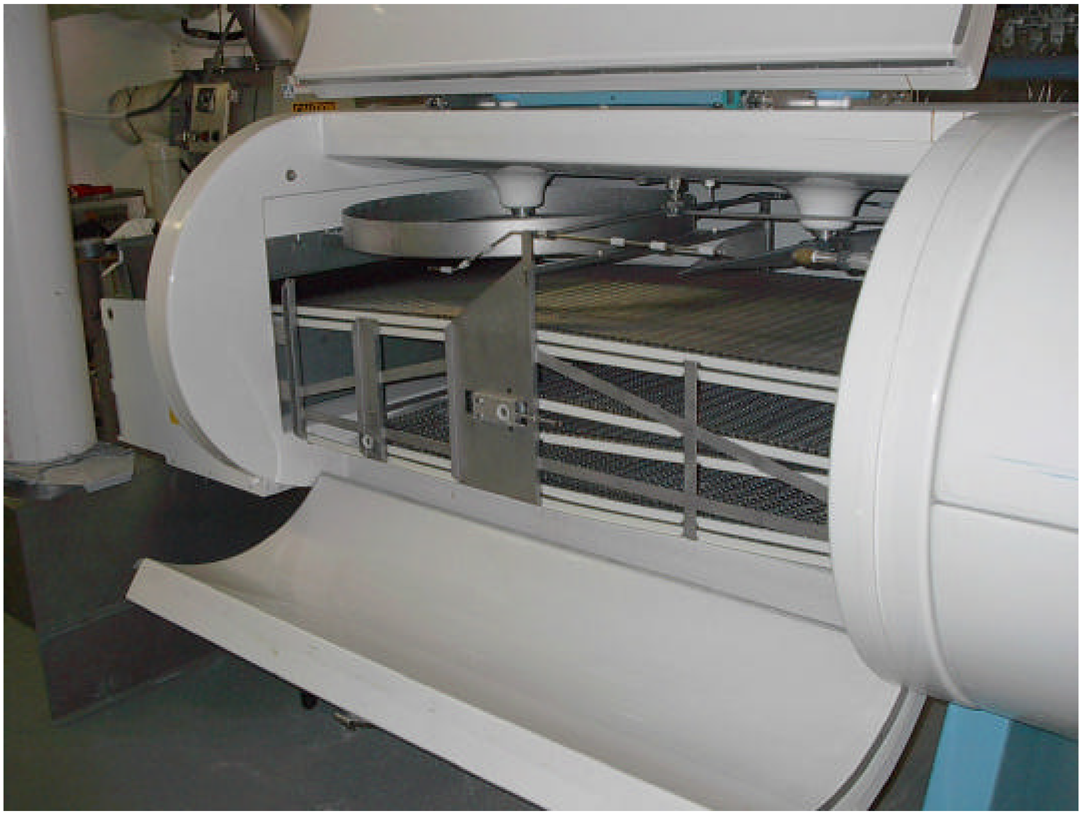

Figure 14. Cryogenic tunnel outfitted with nitrogen and carbon dioxide to rapidly chill oysters.

Heat Treatment Procedure

Prior to starting the shucking treatments, all valves, vents, and drains were in the off position. No inlets or outlets on the vessel were left open. The following operations were conducted in sequence:

1) Instrumented and placed oysters in retort
2) Closed and sealed retort
3) Started data acquisition system
4) Opened steam supply line at gate valve
5) Turned on vacuum pump water and power
6) Opened vacuum valve to withdraw air from vessel

Table 1. A summary of oyster shucking treatments under Method 1.

Method	Source	Pre-Freeze	Pre-Heat (s)	Steam Injection (s)	Hold (s)	Post-Process Chill (s)	Reps	Banded
1	PC	N	0	30	0	30	3	N
1	PC	N	0	30	0	60	3	N
1	PC	N	0	40	0	60	4	N
1	PC	N	0	50	0	60	4	N
1	PC	N	0	60	0	60	10	N
1	PC	N	0	90	0	60	7	N
1	PC	Y	0	120	0	60	10	N
1	PC	N	15	90	0	60	5	Y
1	PC	N	30	90	0	60	20	Y
1	PC	N	30	0	0	60	4	Y
1	PC	N	60	0	0	60	5	Y
1	PC	N	90	0	0	60	5	Y
1	PC	N	30	75	0	60	5	Y
1	PC	N	0	5	30	0	10	N
1	PC	N	0	10	30	0	41	N
1	PC	N	0	15	30	0	50	N
1	PC	N	0	15	45	0	4	N
1	PC	N	0	5	60	0	5	N
1	PC	N	0	10	60	0	5	N
1	PC	N	0	20	60	0	10	N
1	PC	N	0	45	60	0	8	N
1	PC	N	0	60	90	0	8	N
1	GI	N	0	5	60	0	10	N
1	GI	N	0	15	60	0	10	N
1	GI	N	0	15	90	0	10	N
1	GI	N	0	15	120	0	10	N
1	GI	N	5	15	45	0	8	N
1	GI	N	10	15	60	0	10	N
1	GI	N	20	15	60	0	10	N
1	GI	N	10	10	30	0	10	N
1	GI	N	10	10	60	0	20	N
1	GI	N	15	5	30	0	10	N
1	GI	N	15	5	60	0	10	N
1	GI	N	15	10	60	0	10	N

Table 2. A summary of oyster shucking treatments under Method 2.

Method	Source	Pre-Freeze	Pre-Heat (s)	Steam Injection (s)	Hold (s)	Post-Process Chill (s)	Reps	Banded
2	PC	N	45	30	0	240	15	Y
2	PC	N	30	30	30	240	15	Y
2	PC	N	15	30	60	240	15	Y
2	PC	N	15	30	45	240	8	Y
2	PC	N	15	30	30	240	8	Y
2	PC	N	15	30	45	240	15	Y
2	PC	N	15	45	30	240	15	Y
2	PC	N	15	45	0	240	15	Y
2	PC	N	30	30	0	240	15	Y
2	PC	N	30	45	60	240	7	Y
2	PC	N	60	30	60	240	8	Y
2	PC	N	0	52	90	240	15	Y
2	PC	N	0	45	90	240	15	Y
2	PC	N	0	60	90	240	15	Y
2	PC	N	0	90	60	240	15	Y
2	PC	N	0	120	0	240	15	Y
2	PC	N	0	90	0	240	15	Y
2	PC	N	0	60	60	120	15	Y
2	PC	N	0	120	0	120	7	Y
2	PC	N	0	90	0	120	7	Y
2	PC	N	0	120	0	120	7	Y
2	PC	N	0	90	60	120	7	Y
2	GI	N	0	60	0	120	7	Y
2	TX	N	0	60	60	120	5	N
2	TX	N	0	90	60	120	5	N
2	TX	N	0	120	60	120	5	N
2	TX	N	0	120	60	120	5	N
2	TX	N	0	120	60	120	5	N
2	TX	N	0	90	60	120	5	N
2	PC	N	0	90	60	120	15	N
2	PC	N	0	90	60	120	15	Y
2	PC	N	0	60	60	120	7	Y

7) Captured vacuum by closing vacuum valve and turning off vacuum pump

8) Injected steam into vessel by opening steam inlet ball valve (Method 1) or solenoid valve (Method 2) and closed when needed

9) Held oysters in pressurized vessel for predetermined time (Hold Time)

10) Opened vessel vent valve to release pressure

11) When pressure fell below 2 psi, vacuum pump was switched on, vacuum valve was opened, ice water suction valve was opened and ice water was pulled into retort

12) Oysters were held in ice water for predetermined amount of time

13) Stopped data acquisition

14) Retort lid was loosened and removed; ice water drained from retort

15) Removed oysters from vessel for measurement and analysis

An alternative procedure also was used and this had a pre-heating steam injection prior to pulling a vacuum. By opening the retort's vent, steam was injected through and out of the vessel. The steam inlet and vessel vent solenoid valves were then closed and the vacuum solenoid valve opened to pull residual steam and air out of the vessel. The remainder of the procedure was the same. Results from a typical steam injection, hold and CO_2 chill are presented in (Figure 15). This figure shows an initial steam injection where the internal and external shell temperatures as well as the muscle or soft tissue of the oyster also increase. After the steam treatment, the oysters were removed from the retort and placed in the cryogenic tunnel where the temperatures of the shell and muscle decrease rapidly.

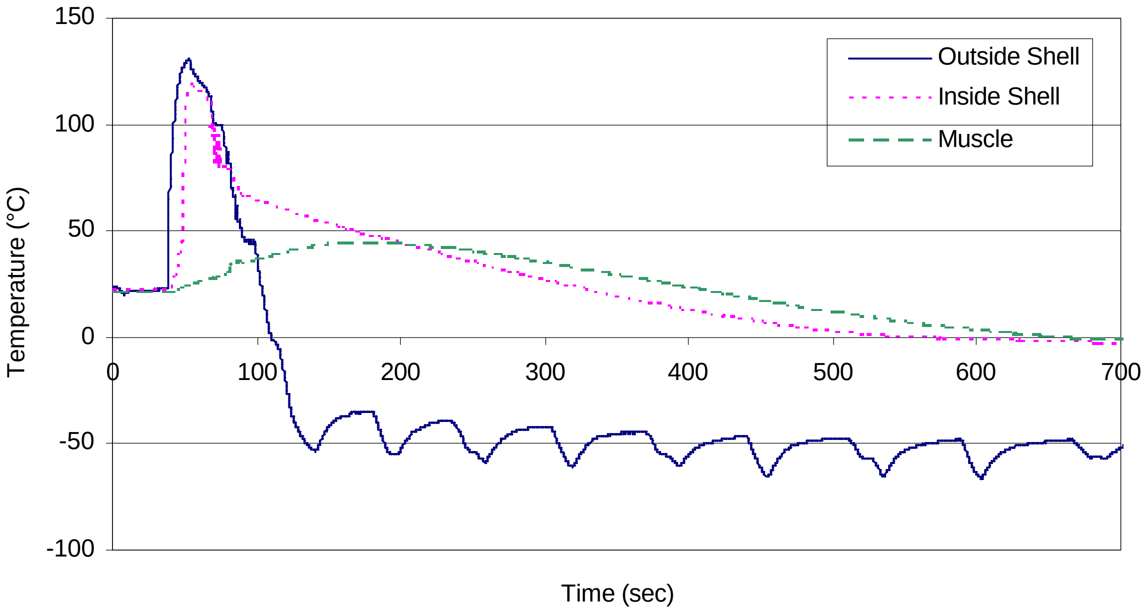

Figure 15. Typical thermal response of Louisiana Gulf Coast oysters (*Crassostrea virginica*) to steam injection, hold and CO_2 chill.

Likewise, results from a typical pre-heat, steam injection, hold and ice water chill are presented in (Figure 16). Here, an initial 30 second pre-heat of the oysters was performed followed by an evacuation of the retort. At approximately 160 seconds, steam was injected for 30 seconds and then held for 30 seconds. After the hold time, the vacuum pump was turned on and ice water was injected into the retort and held for two minutes. The figure shows the temperature of the ice water as the heat from the retort moderated the temperature of the ice water as it entered the vessel.

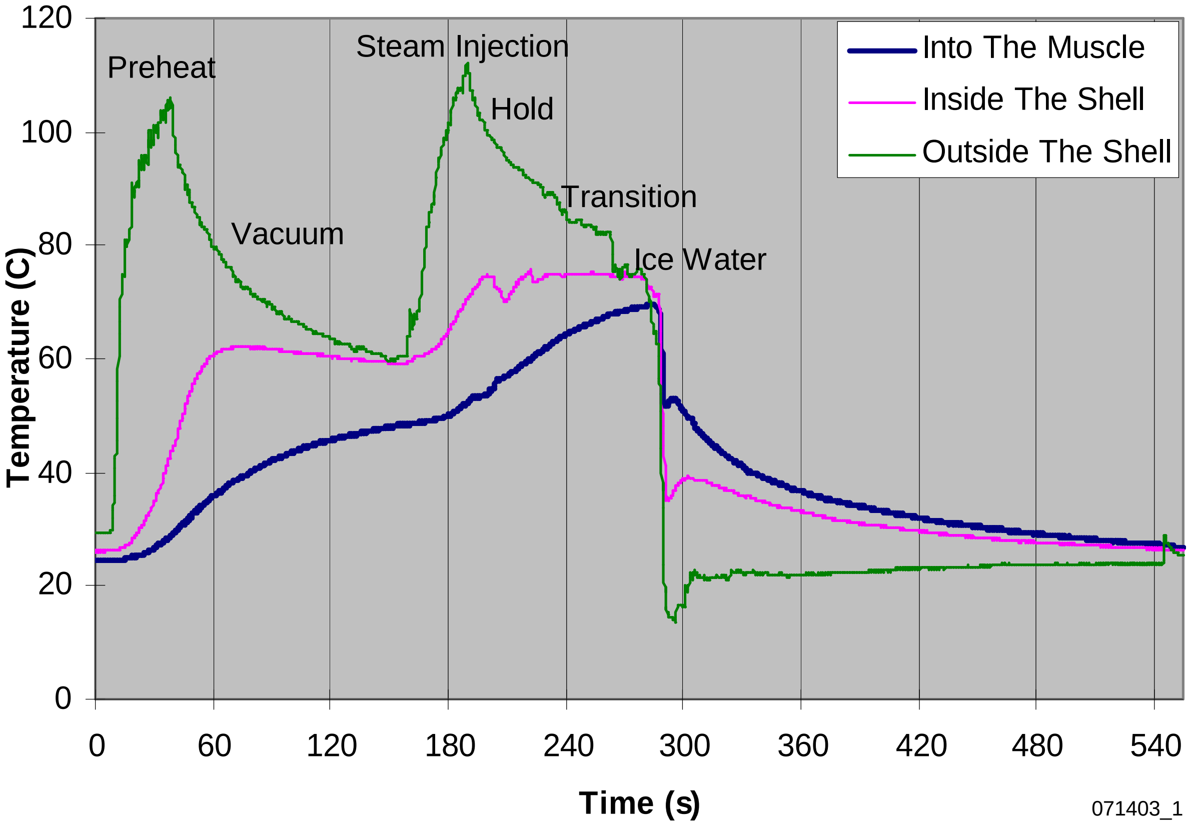

Figure 16. Typical thermal response of Louisiana Gulf Coast oysters (*Crassostrea virginica*) to pre-heat, steam injection, hold and ice water chill.

Determining Relaxation, Degree of Release and Meat Quality

After each treatment, the treated oysters were subjected to thorough analysis to determine degree of relaxation, degree of release and the resulting meat quality. After treatment, it would be advantageous for the oyster to be not only relaxed, but gaping so the meat could easily be removed from inside the shells. For degree of relaxation, the shells of each oyster were squeezed together by hand and any movement of the shells was noted. If no movement resulted, the oyster received a relaxation value of zero. Incremental increases in movement resulted in relaxation values of 1, 2 or 3, with a value of 3.0 given for a fully gaped oyster.

Degree of release was determined by carefully prying the shells of the oyster open and observing how much of the adductor muscle, both opaque and translucent, remained attached to the muscle scar. If the scar was completely free of any muscle, a value of zero was given. If either type of muscle was still attached, a value ranging from 1.0 to 3.0 was assigned. A value of 3.0 indicated that no muscle release was achieved. Degree of release was recorded for both opaque and translucent muscle types for both left and right valves.

Meat quality is a critical index of success for an automated shucking operation. Many consumers prefer oysters raw and any cooking of the oyster is undesirable. The oysters were evaluated for quality by visually observing the mantle and the overall appearance of the oyster meat for any signs of cooking. An untreated oyster was shucked and used for visual comparison. If the oyster looked raw, a value of 1.0 was assigned for quality. Based on guidance from the industry cooperators in the project as to what level of cooking might be acceptable, if, in our judgment, less that 10% cooking had occurred, we assigned a value of 2.0 or less for quality. If we felt that the level of cooking was unacceptable, a value of greater than 2.0 was assigned up to a maximum value of 3.0.

Microbial Analysis

Standard measures of shelf-life, including stiffness and microbial content, were made during the shelf-life studies. Total plate counts were used to measure shelf-life at 0, 3, 7, 10 and 14 days. Total plate count analyses were conducted using standard procedures by Dr. Marlene Janes with the LSU Department of Food Science.

Oyster meats were weighed in grams and an equal amount in milliliters of Phosphate Saline Buffer (PBS, pH = 7.0 buffer) was added. Each oyster sample was stomached and homogenized for two minutes. Decimal dilutions were made and plated onto nutrient agar with 3% NaCl. The log CFU/g of each sample was determined after incubating for 48 h at 37?C by counting the colonies on each plate. Figure 17 shows typical results of the treated oysters as compared to controls. For this particular treatment, the treated oysters exhibited higher total plates counts for the first seven days of storage but dropped below the controls after seven days of storage.

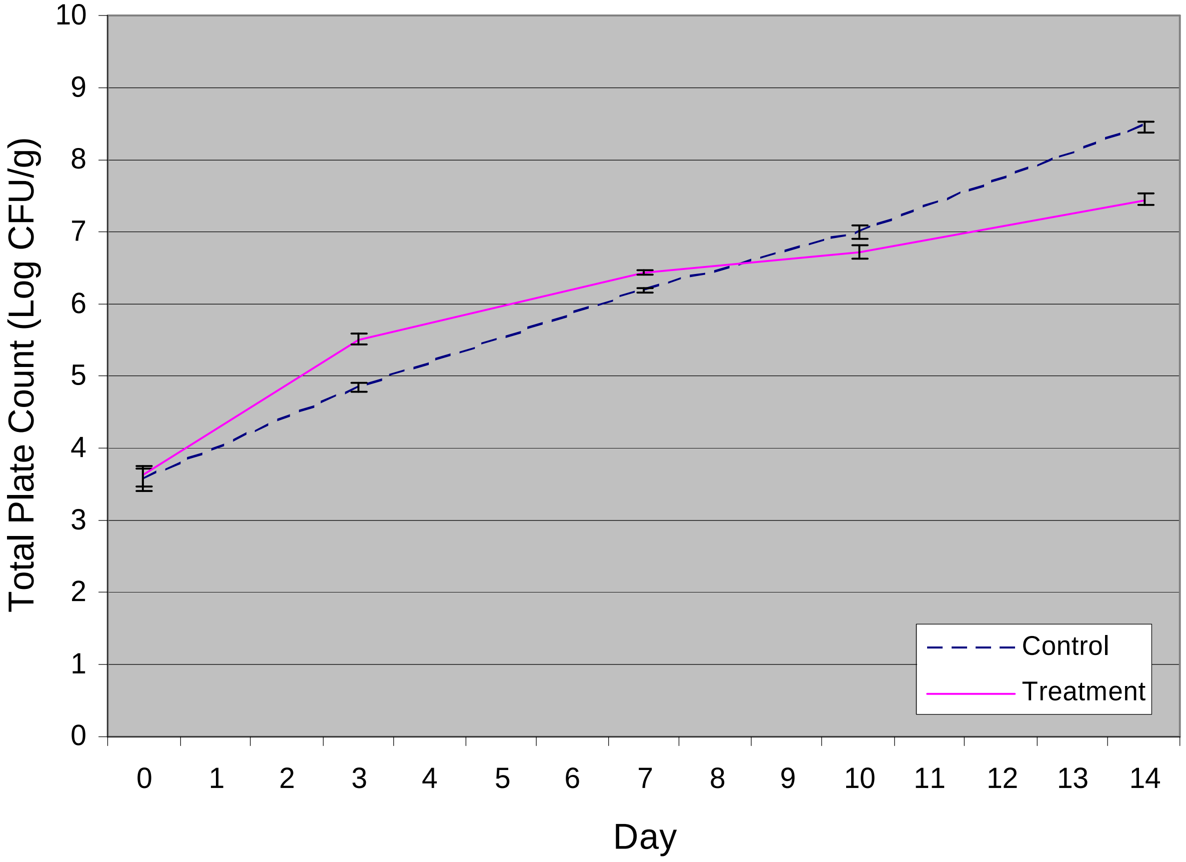

Figure 17. Typical total plate count for Louisiana Gulf Coast Oysters (*Crassostrea virginica*). This particular run was for oysters with a 15 second pre-heat, 30 second steam injection, 60 second hold and 4 minutes ice water bath.

Compression Analysis

One of the objectives of this study was to produce a shucked oyster that closely resembled an unprocessed raw oyster. One of the indices of this is toughness, which is related to texture. Compressive resistance is one quantitative measure of toughness. The tougher a product is, the more it will resist compression and thus, the values of compressive resistance will be greater than that of a tenderer product. A Chatillon Vitrodyne automated compression device (Figure 18) was used to quantify stiffness of raw and steam-treated oysters for improved repeatability and to eliminate the need for human subjects. Treated and untreated oysters were loaded onto the Vitrodyne compression analysis machine and subjected to cyclic compression. Each oyster was placed on the compression platform with the adductor muscle directly beneath the load plate (Figure 19), preloaded to five grams and subjected to cyclic compression for a distance of 5000 µm/stroke at a rate of 5000 µm/second for ten to twenty cycles.

Each processed oyster was tested and the results were plotted (Figure 20) comparing the treated oysters to the controls within size classes of small (left valve height (LVH) < 85 mm), medium (85 mm = LVH < 100 mm) and large (LVH = 100 mm). From this graph, it can be seen that the treated oysters consistently provided more resistance to compression than the raw controls over the entire twenty cycles. In this case, it could be concluded that this treatment caused a toughening of the oysters, which is not a desirable attribute.

Oyster Physical Observations

It was anticipated that the size and shell thickness (influenced by growing conditions) of the oysters would affect how they responded to the various heating regimes. Therefore, after treatment, physical characteristics of each oyster, such as height, length and thickness of both

Figure 18. Vitrodyne hardware and setup for performing compressive resistance testing on oysters.

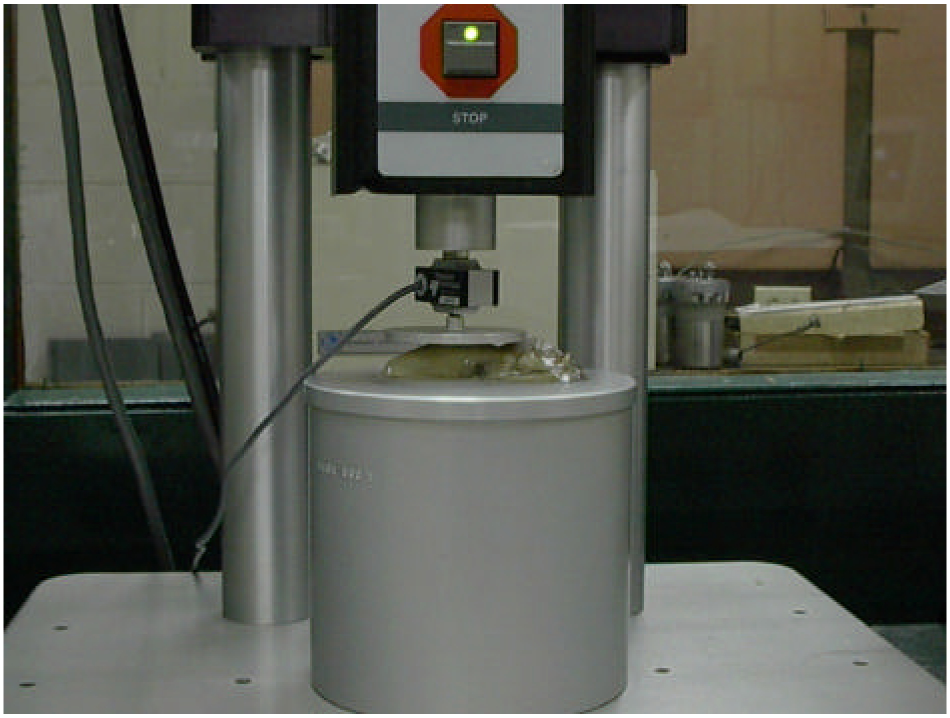

Figure 19. Oyster meat loading onto Vitrodyne compression analysis machine.

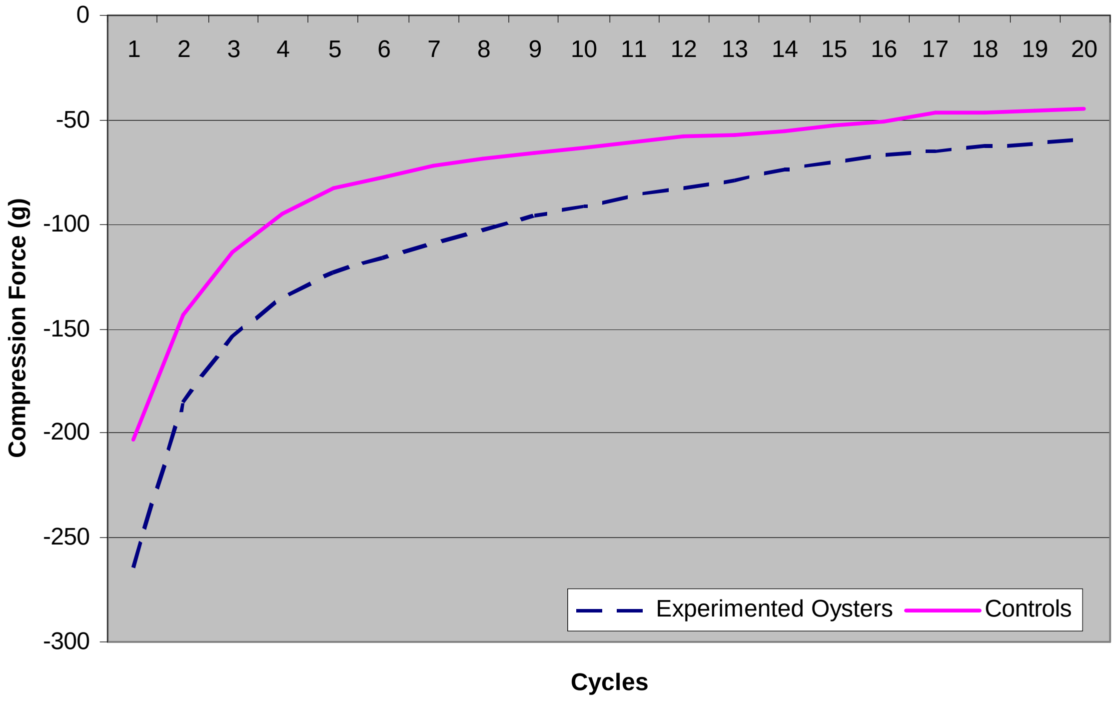

Figure 20. Typical compressive resistance of Louisiana Gulf Coast oysters (*Crassostrea virginica*). This particular run was for large oysters with a 15 second pre-heat, 30 second steam injection, 30 second hold and 4 minutes ice water bath.

shells at the muscle scar were measured with digital calipers (Figure 21) and recorded. Measurements were rounded to the nearest one-tenth of a millimeter. The digital calipers used to measure the thickness of the shells had to be modified to enable a measurement of thickness at the muscle scar without hitting other parts of the shell (Figure 22).

Summary and Conclusions

Instrumentation techniques were developed to measure temperature both within and without live oysters and to record those temperature readings on a datalogger. Equipment was designed and set up to thermally shuck oysters via steam and rapidly cool them with nitrogen, carbon dioxide and ice water following treatment. Methods were established for determining


Figure 21. Digital calipers used to measure height and length of oysters.


Figure 22. Digital calipers used to measure thickness of oyster shell at muscle scar.

and quantifying the ability of the shucking treatments to effect oyster relaxation and muscle release, as well as the resulting affects on meat quality. The effect of the thermal shucking treatments on microbial flora also was quantified over a storage period of 14 days. Methods also were successfully established for determining textural changes in oysters as a result of processing. Future work might include running *Vibrio* specific tests for microbial analysis and using a shear test for the textural analysis to simulate chewing.

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Chapter 4. The Influence of a Thermal Shucking Process on the Reduction of Bacteria in Louisiana Gulf Coast Oysters (*Crassostrea virginica*)

Introduction

The ability to keep and preserve food has been essential from the beginning of time. Drying has long been a preservation method of choice since the reduction water activity in food products deprives microorganisms needed moisture for survival. With fish products, drying is still used as a preservation method (Orejana and Embuscado, 1982). Shellfish, however, require more modern techniques to preserve flavor and quality. The shelf-life of shellfish is still a major concern (Anonymous, 1977; Sturmer and Vaughan, 1997; Heath, 1998) but has been extended by a variety of means. The most common way of extending the shelf-life of shellfish is by reducing the temperature of the shellfish by either icing, refrigerating or freezing (Anonymous, 1975; Boyd, Wilson et al., 1980; Anonymous, 1985; Hackney, 1990; Miget, 1991; Bird, Arnold et al., 1992; Ralonde, Cochran et al., 1993; Anonymous, 1996; Park and Lanier, 2000.) Other preservation techniques involve the addition of chemicals such as trisodium phosphate, salt, vinegar, chitosan and smoke which inhibit the growth of microorganisms (Maff, 1972; Hackney, 1990; Ahn and Lee, 1992; Phelps, 1994; Sugumar, Jeyasekaran et al., 1994; Chen, Liau et al., 1998; O'Gorman, Kerry et al., 1999b; Capita, Alonso et al., 2002). Mild heat treatments also have shown an ability to reduce bacteria in shellfish while maintaining an essentially raw product (Goldmintz, 1978; Goldmintz and Ernst, 1979; Paparella, 1980). As technology has advanced in recent years, more modern techniques have been utilized to increase the shelf-life of shellfish. Advances in packaging technologies have yielded modified atmosphere packaging, vacuum packaging and hypobaric storage as methods to improve shelf-life (Stroud, 1983; Flick, Hong et al., 1991; Cornelis Keizer and Barbe, 1998). Irradiation also has been tested and shows great promise as a means of reducing bacteria and extending shelf-life in seafood (Ehlermann and Diehl, 1977; Hobbs and Ley, 1985.; Dixon and Rodrick, 1990; Dixon and Rodrick, 1992; Colby, Enriquez-Ibarra et al., 1993). Pressure, both low (<50 psi, in conjunction with steam) and high (>30,000 psi), also has been investigated as a means of extending the shelf-life of shellfish with the added benefit of facilitating shucking in many cases (Anonymous, 1979; Colby, Enriquez-Ibarra et al., 1993; Haejung, 1998; O'Gorman, Kerry et al., 1999a).

Present Study

This study evaluated the effects of a heat-cool process on American oysters (*Crassostrea virginica*) to effect shucking and reduce bacteria during storage. One of the objects of the study was to cause the relaxation and release of the adductor muscle from the shell; in short, a process that would automate oyster shucking. The methodology for this study is described in detail in Chapter 3 and uses a steam retort under different heating and low pressure regimes to effect shucking. Another of the objectives of this study was to determine the effect the treatments had on bacteria over 14 days of storage at 2°C.

Materials and Methods

Fifteen oysters (three for each of five storage periods; 0, 3, 7, 10 and 14 days) from each treatment were individually placed in zippered plastic bags, labeled and transported on ice to the LSU Agricultural Chemistry Department for analysis.

The oyster meats were weighed in grams and an equal amount in milliliters of phosphate buffer solution (pH = 7.0 buffer) was added. Each oyster sample was stomached and homogenized for two minutes. Decimal dilutions were made and plated onto nutrient agar with 3% NaCl. The log CFU/g of each sample was determined after incubating for 48 h at 37?C by counting the colonies on each plate.

Results and Discussion

Figures 23-33 illustrate the effect the various thermal oyster shucking treatments had on the survival and growth of bacteria as measured by total plate count (TPC). For the initial counts on day zero, all of the treatments were either equivalent to the controls or had lower ($P<0.05$) counts than the controls as illustrated in Figures 25, 26, 27, and 31. After three days of storage, two treatments showed increased levels of bacteria ($P<0.05$) over the controls (Figures 25 and 32) and six treatments showed decreased levels of bacteria ($P<0.05$) over the controls (Figures 23, 24, 27, 28, 31, and 33). The remaining treatments showed no significant differences. After seven days of storage, four treatments showed increased levels of bacteria ($P<0.05$) over the controls (Figures 29, 30, 31, and 32) and two treatments showed decreased levels of bacteria ($P<0.05$; Figures 27 and 28). After ten days of storage, five treatments showed increased levels of bacteria ($P<0.05$) over the controls (Figures 23, 28, 30 and 33) and only one treatment showed decreased levels of bacteria ($P<0.05$; Figure 31). After 14 days of storage, four treatments showed increased levels of bacteria ($P<0.05$) over the controls (Figures 23, 25, 26, and 30) and two treatments showed decreased levels of bacteria ($P<0.05$; Figures 27 and 32). Statistical analysis to determine differences between treatments was not possible, since treatments were conducted on different days and over several weeks. Bacterial loads vary depending on the age of the oysters and the time and location of harvest. Thus, treatments could only be compared to the corresponding controls.

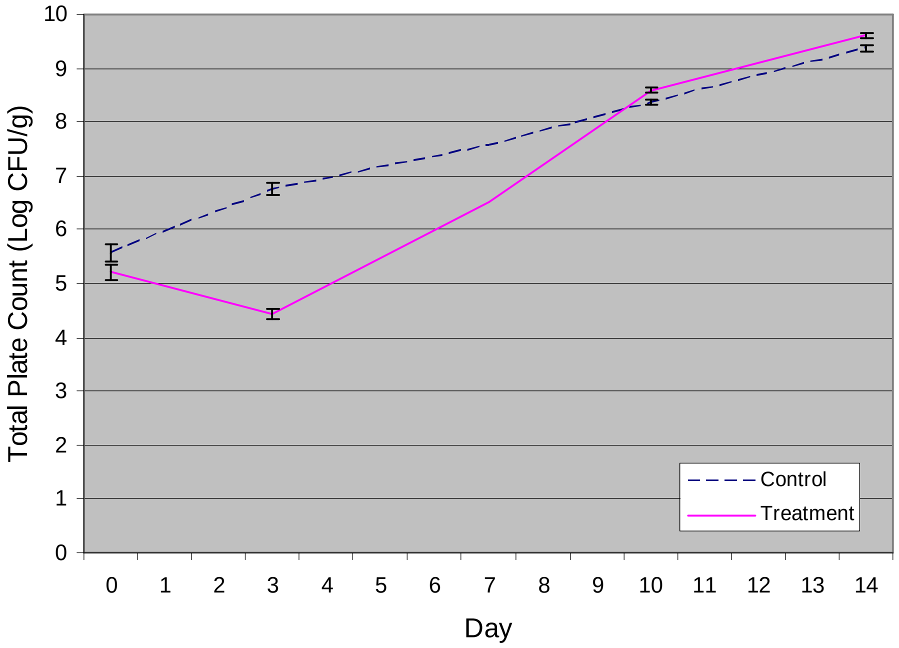

Figure 23. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with no pre-heat, a 60 second steam injection, a 60 second hold and 2 minutes ice water bath.

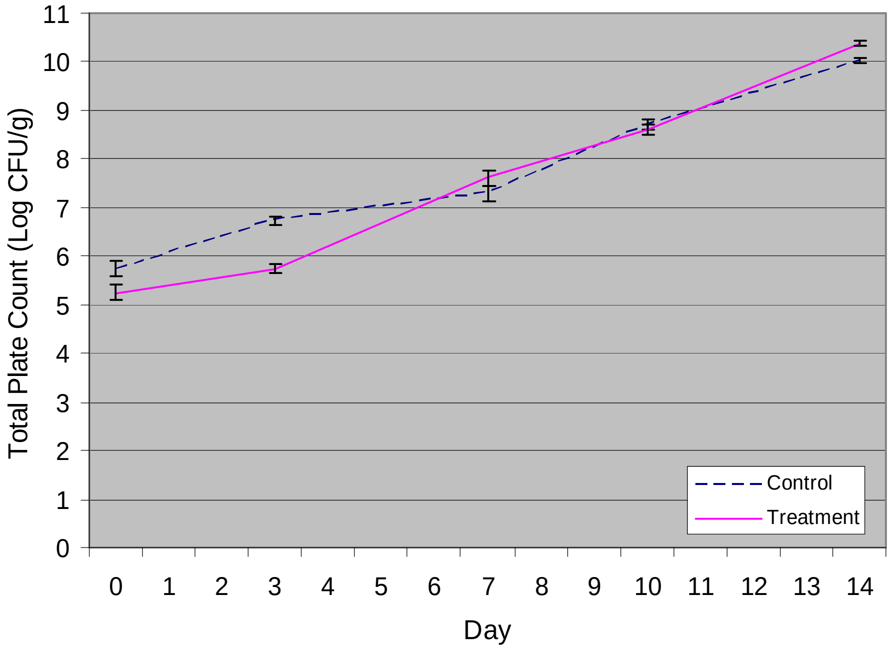

Figure 24. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with no pre-heat, a 90 second steam injection, no hold and 4 minutes ice water bath.

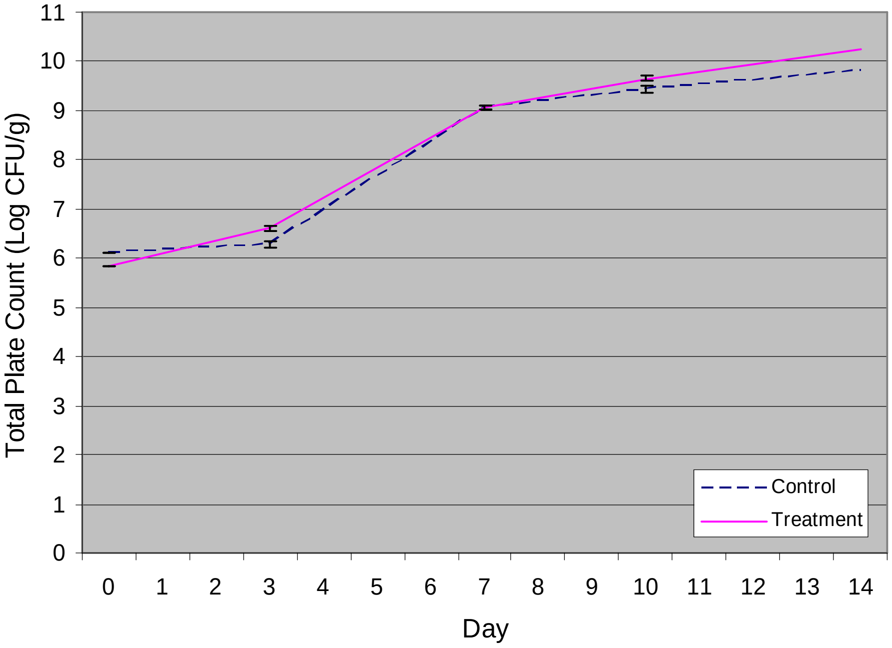

Figure 25. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with no pre-heat, a 120 second steam injection, no hold and 4 minutes ice water bath.

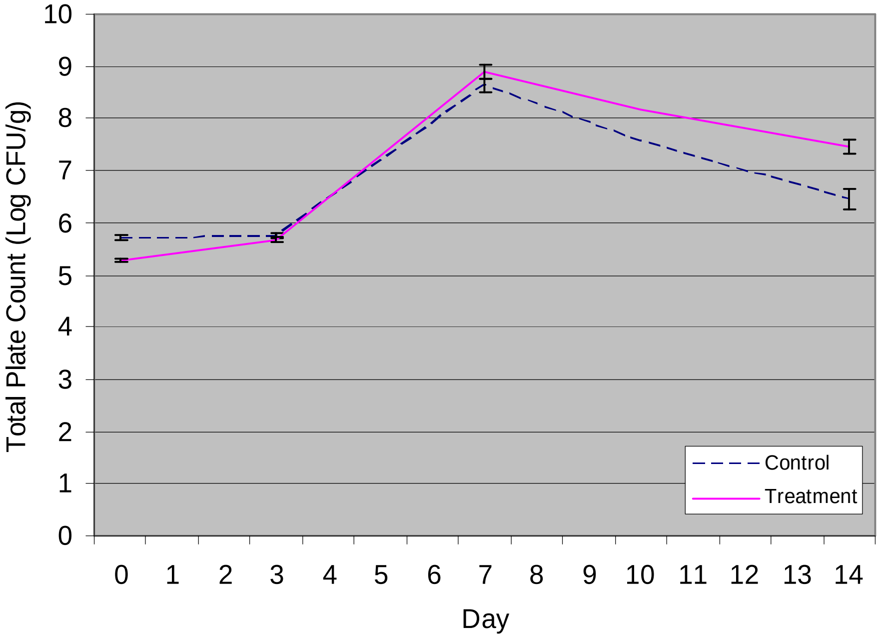

Figure 26. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with no pre-heat, a 90 second steam injection, a 60 second hold and 4 minutes ice water bath.

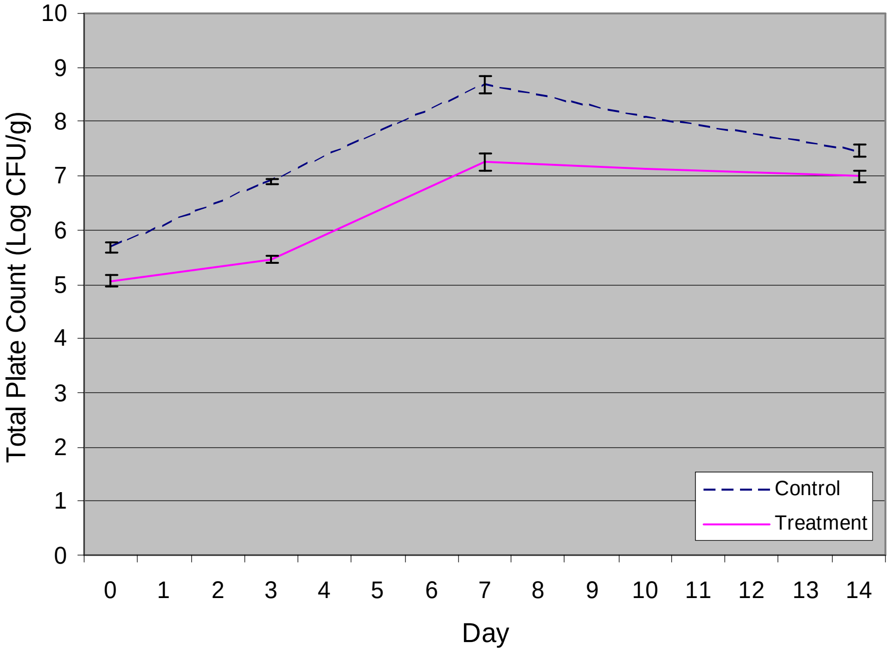

Figure 27. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with no pre-heat, a 60 second steam injection, a 90 second hold and 4 minutes ice water.

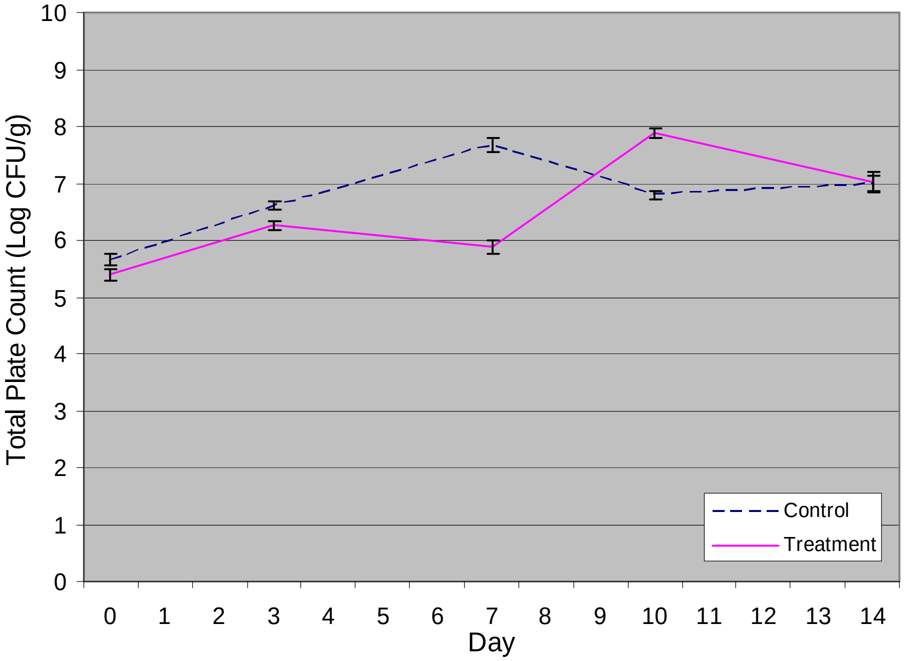

Figure 28. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with a 30 second pre-heat, a 30 second steam injection, no hold and 4 minutes ice water.

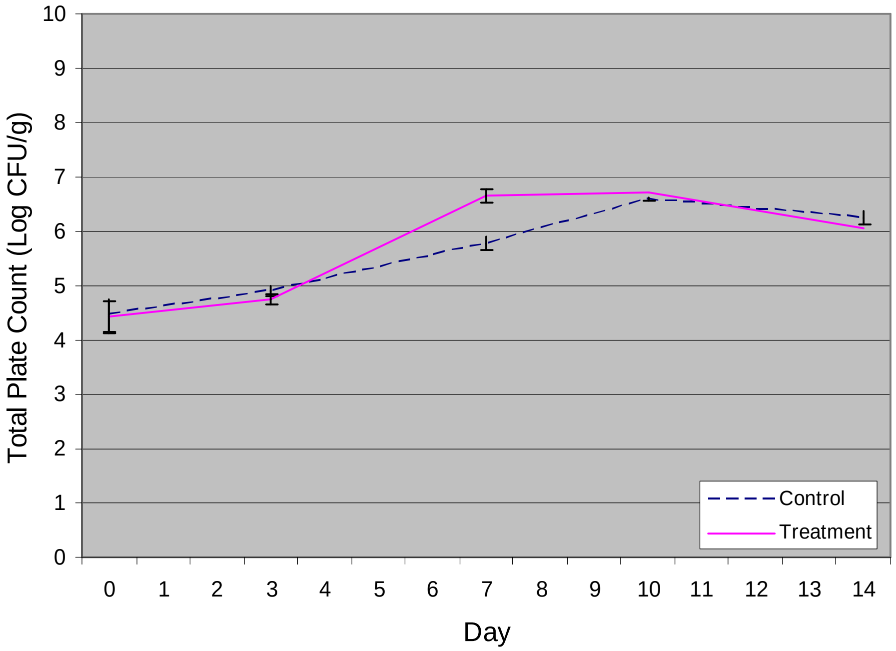

Figure 29. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with a 15 second pre-heat, a 45 second steam injection, no hold and 4 minutes ice water.

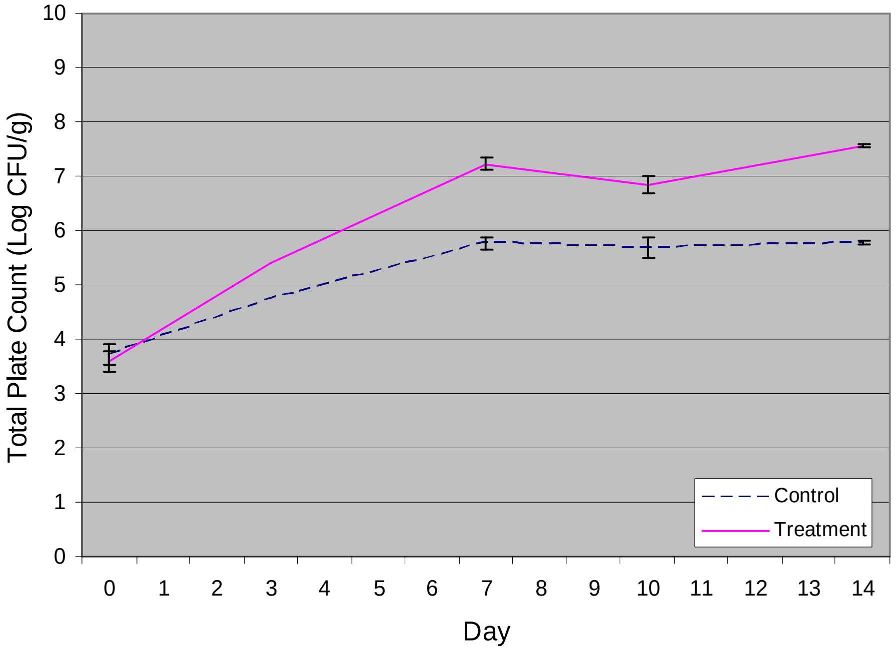

Figure 30. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with a 15 second pre-heat, a 45 second steam injection, a 30 second hold and 4 minutes ice water.

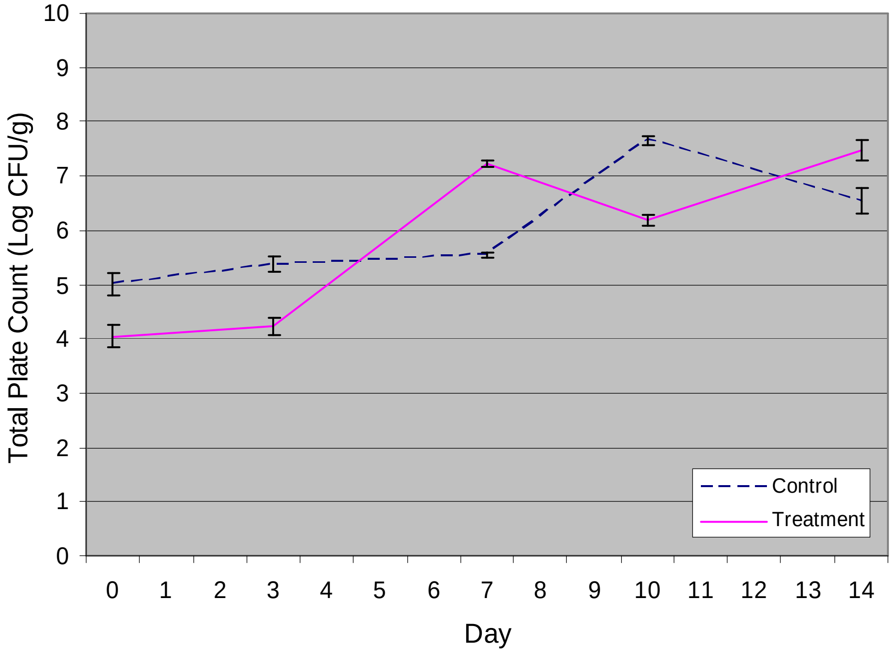

Figure 31. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with a 15 second pre-heat, a 30 second steam injection, a 45 second hold and 4 minutes ice water.

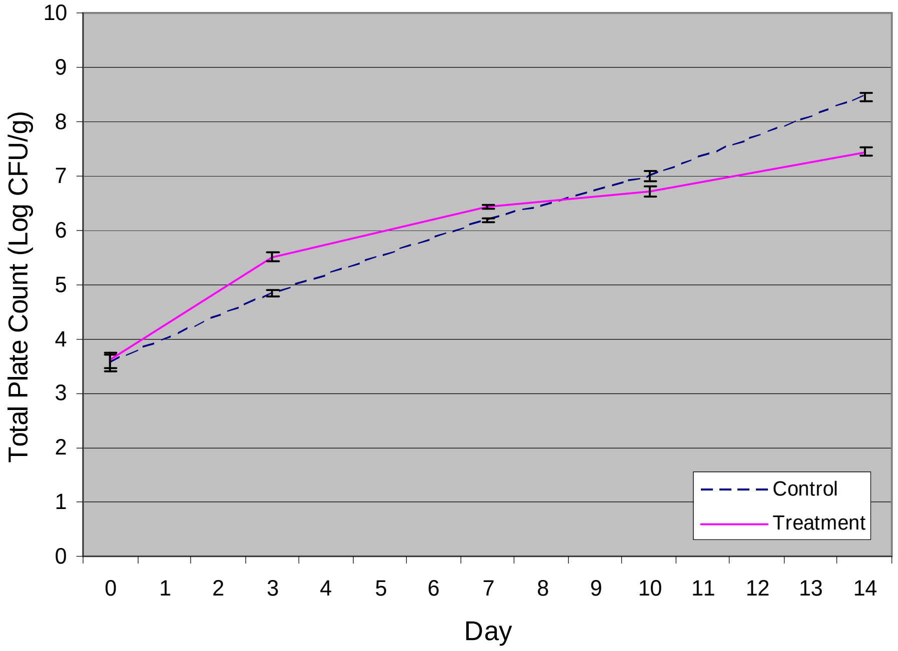

Figure 32. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with a 15 second pre-heat, a 30 second steam injection, a 60 second hold and 4 minutes ice water.

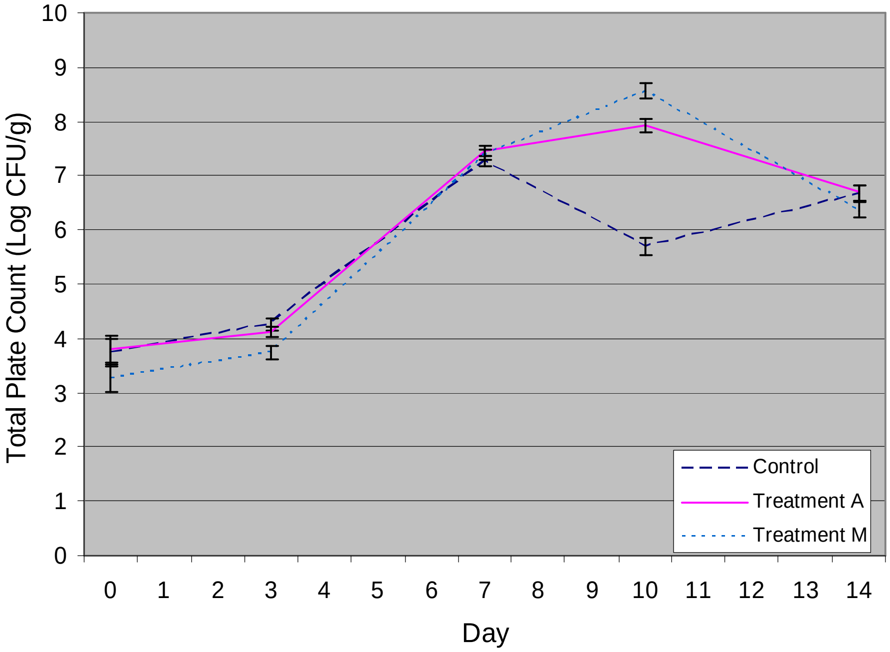

Figure 33. Total plate count for Louisiana Gulf Coast oysters (*Crassostrea virginica*) over 14 days of storage at 2°C. Oysters were treated with a 45 second pre-heat, a 30 second steam injection, no hold and 4 minutes ice water.

Another way to view the effects of the treatments on bacteria in oysters is to look at the difference between the total plate counts (TPCs) for all of the treatments versus the controls as plotted against the mean maximum inside shell temperature of the oysters for each storage period (Figures 34-38). Delta log CFU/g represents the TPC values for the controls minus the TPCs for the treated oysters. Thus, positive results from the graph would indicate a lower TPC for the treatment as compared to the control. The mean maximum inside shell temperature is the average of the maximum inside shell temperatures as measured with thermocouples into the shell during the treatments of the instrumented oysters. Typically, six oysters per treatment were instrumented. It was felt that the maximum temperature achieved inside the shell during treatment would be the best measure of the effect of the treatment on TPC. Muscle temperatures also were measured and recorded, but felt to be more variable due to the difficulty of placing the thermocouple in the same location in each of the oysters. Since the oysters are closed at the time of thermocouple insertion, the exact location of the point of temperature measurement is unknown and variable. Even when the thermocouple was placed in the muscle, the actual depths inside the muscle varied thus affecting the temperature measured. Placement of the thermocouple in the same location on the inside of the shell of the oysters was more consistent and repeatable.

In Figure 34 for Day 0, it can be seen that the magnitude of most of the data points are very close to each other and that there is an overall positive trend to the data, indicating that the

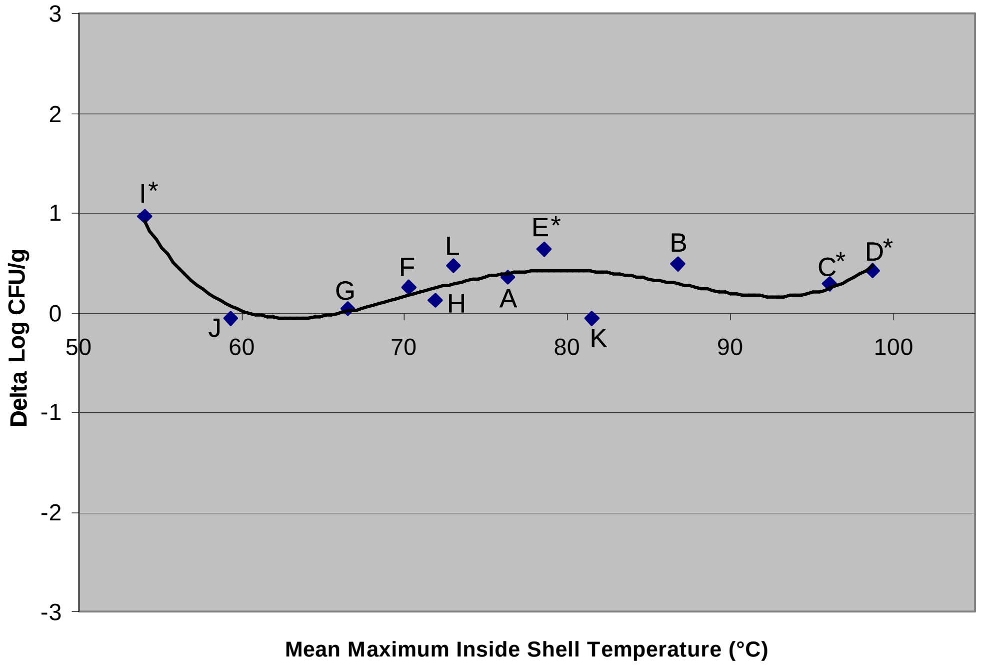

Figure 34. Graphical comparison of initial Total Plate Counts for treated and control oysters. Each data point represents a treatment comparison to a control. The treatments corresponding to the data points are labeled and marked with an * if significantly different (P<0.05) from the control. Positive values represent a reduction in TPC for the treated oysters for the indicated storage period.

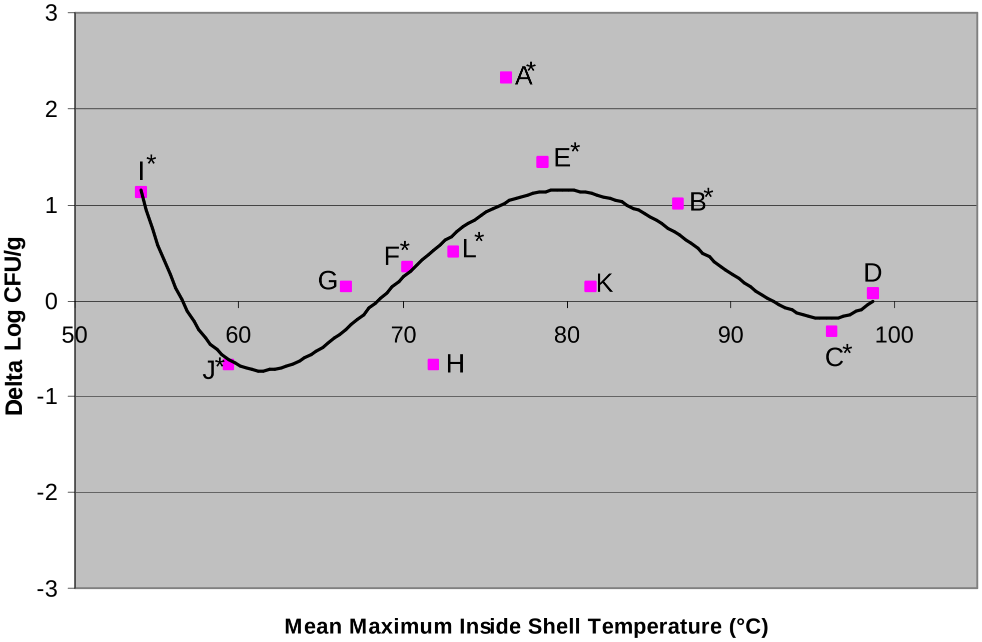

Figure 35. Graphical comparison of Total Plate Counts for treated and control oysters after 3 days of storage. Each data point represents a treatment comparison to a control. The treatments corresponding to the data points are labeled and marked with an * if significantly different (P<0.05) from the control. Positive values represent a reduction in TPC for the treated oysters for the indicated storage period.

treatments on Day 0 as a whole had lower TPCs than the controls. In particular, Treatments C, D, E and I were significantly different (P<0.05) from the controls. The data points were fitted with a fourth order polynomial curve.

After three days of storage, as depicted in Figure 35, the data start to exhibit some spread. Six of the treatments showed significant (P<0.05) reductions in TPC over the controls. Four of these treatments (A, B, E, and I, as identified in Table 3) had bacterial counts less than one order of magnitude than the controls. Two of the treatments (C and J) resulted in significant increases (P<0.05) in TPC over the controls, but were not greater than one log difference from the controls. The data points were fitted with a fourth order polynomial curve.

Table 3 is a summary of the oyster treatments that also were tested for shelf-life. The treatment code relates to the date and run number for that particular date. Pre-heat is the time in seconds that the oysters were heated with vented steam. Steam injection is the time in seconds that steam was injected under pressure into the retort. The hold time is the amount of time in seconds that the oysters were held under pressure after the steam was shut off. The post- process chill is the time in seconds that the oysters were chilled after treatment in an ice water bath. Reps is the number of oysters subjected to a particular treatment. Relaxation is the average of the relaxation values for all of the oysters subjected to a particular treatment. Relaxation values range from 0 (not relaxed) to 3 (fully gaped). The ARV is the average of the average release values for each of the oysters subjected to a particular treatment. The ARV ranged from 0 (full release of both the translucent and opaque adductor muscle from both valves) to 3 (no release of the translucent or opaque adductor muscles from either of the two valves). Quality is the average value of the visual quality of all of the oysters subjected to a particular treatment. Quality values were 1 (essentially raw), 2 (slightly cooked but acceptable) and 3 (cooked and unacceptable). Success is the percentage of oysters in a particular treatment that met the conditions of ARV = 1.0 and Quality = 2.00.

Figure 36 shows TPC results after seven days of storage. Three treatments (A, E, and F) showed TPCs less than the controls by more than one log and two treatments (H and I) resulted in bacteria levels greater than the controls by more than one log. Seventy-five percent of the treatments, however, resulted in TPCs greater than the controls. The data points were fitted with a second order polynomial curve.

Table 3. A summary of oyster shucking treatments.

Treatment	TRT Code	Pre-Heat (s)	Steam Injection (s)	Hold (s)	Post-Process Chill (s)	Reps	Relaxation	ARV	Quality	Success (%)
A	061203	0	60	60	120	15	0.20	1.18	1.86	40
B	061303	0	90	0	240	15	0.37	0.67	2.37	47
C	061603	0	120	0	240	15	1.00	0.35	2.93	0
D	061703	0	90	60	240	15	0.60	0.20	3.00	0
E	061803	0	60	90	240	15	0.00	0.46	2.67	33
F	062603	30	30	0	240	15	0.50	1.00	1.80	33
G	063003	15	45	0	240	15	0.07	0.33	2.10	67
H	070103	15	45	30	240	15	0.20	0.30	2.70	27
I	070703_2	15	30	45	240	15	0.47	0.25	2.10	47
J	071003_A	15	30	60	240	15	0.07	1.20	1.50	33
K	071403_A	45	30	0	240	15	0.33	0.22	2.50	27
L	071403_M	30	30	30	240	15	0.13	0.70	2.37	40

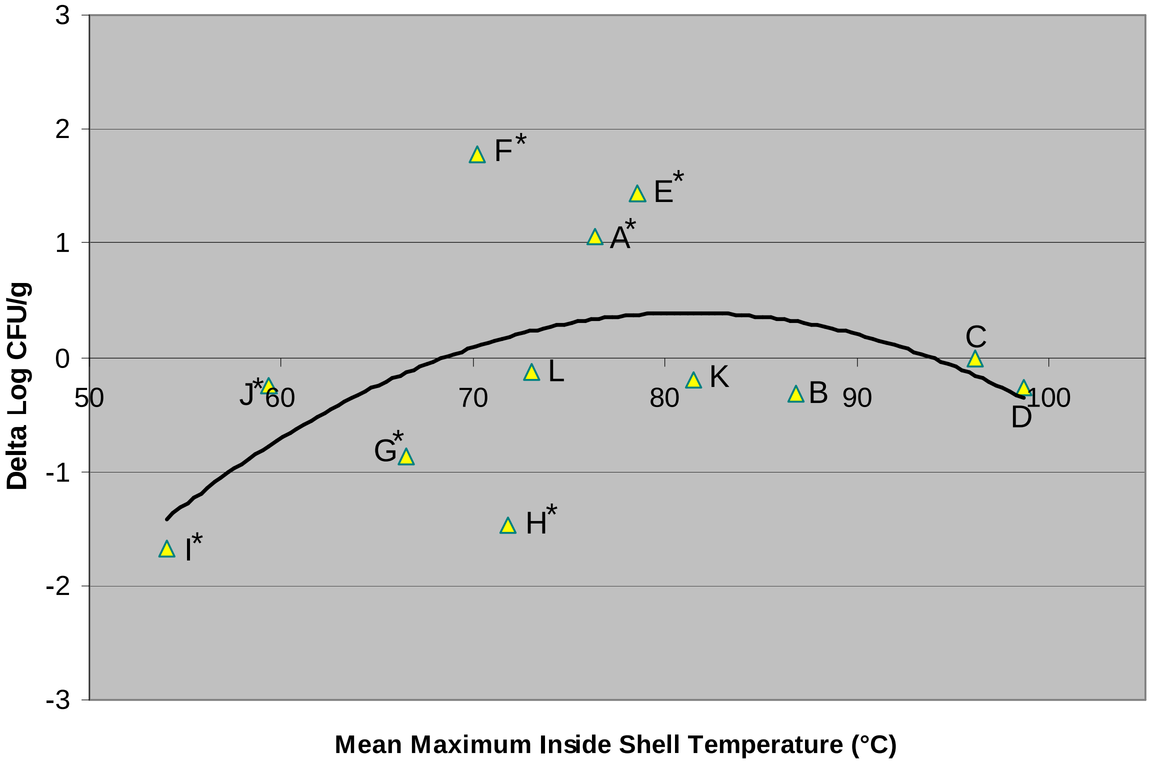

Figure 36. Graphical comparison of Total Plate Counts for treated and control oysters after 7 days of storage. Each data point represents a treatment comparison to a control. The treatments corresponding to the data points are labeled and marked with an * if significantly different (P<0.05) from the control. Positive values represent a reduction in TPC for the treated oysters for the indicated storage period.

After ten days of storage, TPCs for four of the treatments (F, H, K and L) exceeded the controls by more than one log (Figure 37). Interestingly, this occurred in the maximum inside shell temperature range between 70°C and 80°C with one treatment approaching TPCs of three orders of magnitude greater than the control. Only two treatments (E and I) resulted in bacteria levels significantly (P<0.05) less than the control. The data points were fitted with a fourth order polynomial curve.

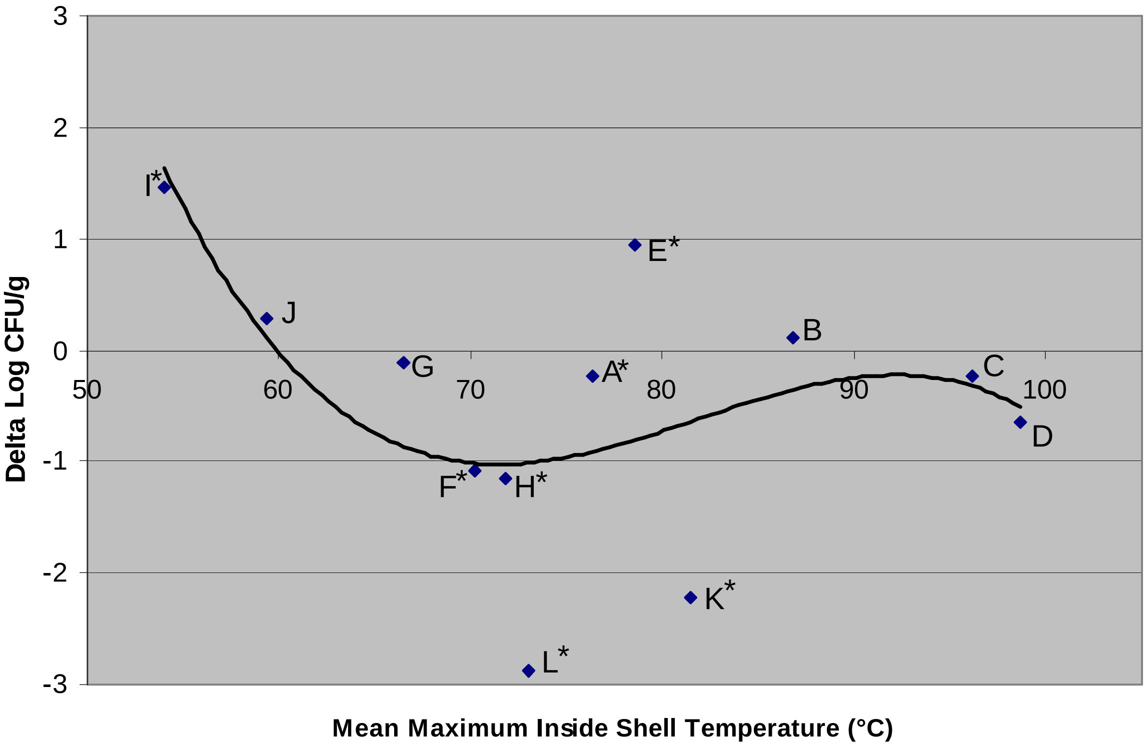

Figure 37. Graphical comparison of Total Plate Counts for treated and control oysters after 10 days of storage. Each data point represents a treatment comparison to a control. The treatments corresponding to the data points are labeled and marked with an * if significantly different (P<0.05) from the control. Positive values represent a reduction in TPC for the treated oysters for the indicated storage period.

By fourteen days, the TPCs for most of the treatments seemed to re-converge with the controls (Figure 38). Four of the treatments (A, C, D and H) were significantly greater than the controls but only two of the treatments (D and H) exhibited TPCs greater than one log compared to the controls. Two of the treatments (E and J) resulted in significantly lower (P<0.05) TPCs over the controls. The TPCs for 75% of the treatments were within one order of magnitude of the controls. The data points were fitted with a fourth order polynomial curve.

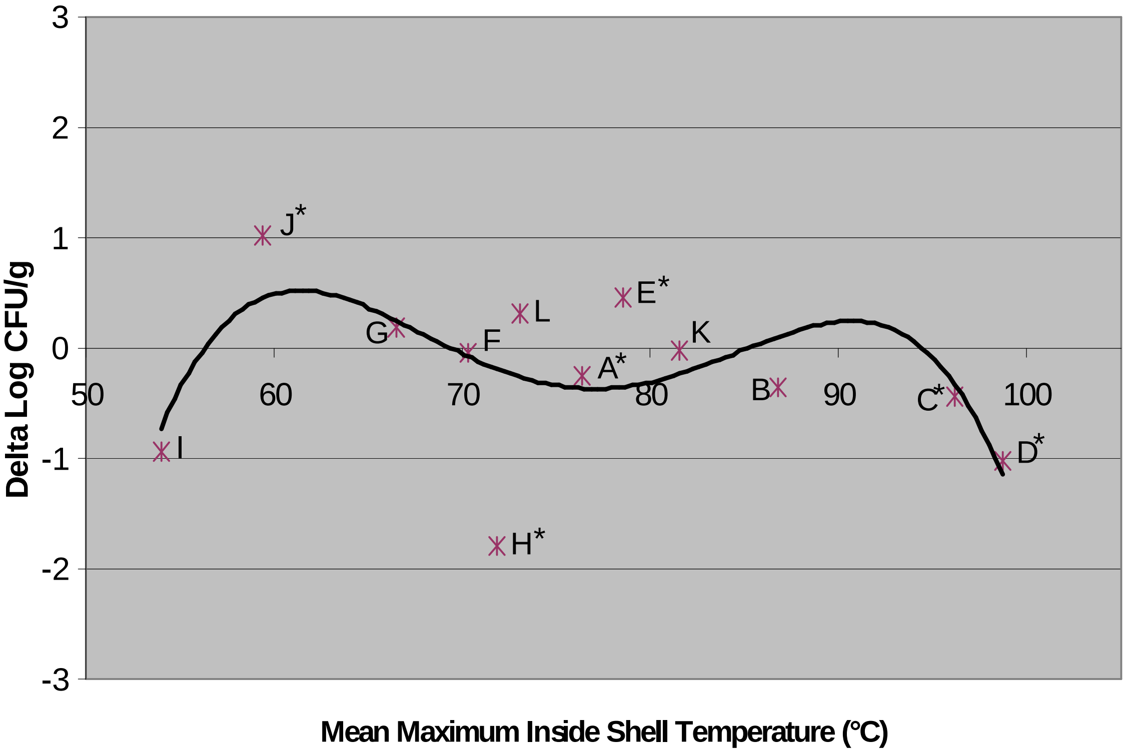

Figure 38. Graphical comparison of Total Plate Counts for treated and control oysters after 14 days of storage. Each data point represents a treatment comparison to a control. The treatments corresponding to the data points are labeled and marked with an * if significantly different (P<0.05) from the control. Positive values represent a reduction in TPC for the treated oysters for the indicated storage period.

Summary and Conclusions

Spoilage bacteria can dramatically reduce the shelf-life of raw oysters. Processes have been developed to control, reduce and eliminate spoilage bacteria from oysters. A couple of these processes are in commercial operation and have been successful in extending the shelf-life of oysters from one week to up to three weeks.

The research from this study has quantified the effect of several mild steam shucking treatments on the levels of bacteria in oysters over 14 days of storage. For some of the treatments, total plate counts for the treated oysters remained below the controls for the entire storage period. Other treatments showed the opposite trend, with treatments resulting in increased total plate counts over the controls. Many of the treatments, however, varied little from the controls and showed no overall effect on the levels of bacteria in the oysters over the two weeks of storage.

Treatments A and E, in particular, resulted in overall improved shelf life over the controls for the duration of the study. From Table 3, it can be seen that overall Treatment A had good releases (ARV=1.18), resulted in acceptable quality (Quality=1.86) and 40 percent of the oysters from that particular treatment met both the qualifications for success (ARV=1.0, Quality=2.0). In contrast, although Treatment E caused bacteria levels to decline during storage compared to the controls, the overall resulting quality of the oysters was poor (Quality=2.67). This treatment caused a cooking of the oysters and would be commercially unacceptable.

Equally important is to understand which treatments resulted in reduced shelf life of the oysters. Over the 14 days of storage, Treatment H consistently resulted in higher levels of bacteria in the treated oysters versus the controls. In addition, after 10 days of storage, Treatments L and K resulted in bacteria levels greater than two orders of magnitude higher than the controls.

From these results, indications are that a particular microorganism might be confounding the results by surviving the mild heat treatment and then growing with less competition in a refrigerated environment. Additional testing will be conducted to determine if *Pseudomonas spp*., which is thermo-tolerant and psychrotrophic, might be responsible for some of the trends observed.

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Chapter 5. Effectiveness of a Heat/Cool Technique for Shucking Oysters

Introduction

Oysters have long been sought after for their flavor and aura but only in the last 50 years have techniques for shucking oysters been revolutionized by modern technology (Paparella et al., 1970; Spracklin, 1971; Singh, 1972; Taylor, 1983; Voisin, 2002; Voisin, 2003b). While such technology has allowed processors to rapidly shuck oysters and in some cases eliminate pathogenic bacteria in the process, its cost prevents many smaller processors from taking advantage of the technology. For example, one of the most successful high pressure techniques requires large capital investment (Voisin, 2003a). Some of the objectives of this study were to investigate a less expensive method of shucking oysters, determine its ability to effect release of the adductor muscle from the shell and evaluate the resulting effect on oyster quality, texture and microflora populations.

Methodology

The methods used to treat the oysters are described in detail in Chapters 3 and 4. A summary of the treatments for the methodologies used is presented in Table 4 and Table 5. In these tables, source is the location where the oysters were harvested (PC – Pass Christian, MS, GI – Grand Isle, LA, TX – Texas). Some of the oysters were pre-frozen with nitrogen or CO_2 and some were pre-heated with vented steam prior to pressurized steam treatment. These also are listed in the table. Steam injection is the amount of time that steam was injected into the retort. Hold is the amount of time that the oysters were left in the retort after steam was shut off. The post-process chill is the amount of time that the oysters were subjected to an ice water bath following treatment. Reps are the number of oysters that were subjected to a particular treatment. Some of the oysters were banded to prevent opening during the steam treatment so as to not cook the oysters.

In order to measure retort and oyster temperature, T-type thermocouples were placed internally to document meat and shell temperature. Selected oysters were instrumented with three thermocouples at positions outside the shell, inside the shell, and inside the center of the oyster to measure the temperature profile dynamics through the shell. Two one-eighth inch holes were drilled in the left valve of the oyster. Both holes were drilled near the outer edge of the oyster, one being horizontal and the other vertical. These holes were then cleaned of any drilling debris and blotted dry of water and oyster liquor. In the horizontal hole, a T-type thermocouple was inserted near the center of the oyster's soft tissue near the adductor muscle. In the second hole, the thermocouple was inserted vertically downward through the right valve until it made contact with the inner shell on the left valve. This thermocouple was then slid about an inch along the inner surface of the shell. Both holes were then dried again and sealed with modeling clay (Figure 39). A third thermocouple was located external to the shell and all three were held in place by a rubber band located near the hinge (Figure 40). Some oysters also were banded posteriorly to prevent opening during the steaming operation.

Table 4. A summary of oyster shucking treatments under Method 1.

Method	Source	Pre-Freeze	Pre-Heat (s)	Steam Injection (s)	Hold (s)	Post-Process Chill (s)	Reps	Banded
1	PC	N	0	30	0	30	3	N
1	PC	N	0	30	0	60	3	N
1	PC	N	0	40	0	60	4	N
1	PC	N	0	50	0	60	4	N
1	PC	N	0	60	0	60	10	N
1	PC	N	0	90	0	60	7	N
1	PC	Y	0	120	0	60	10	N
1	PC	N	15	90	0	60	5	Y
1	PC	N	30	90	0	60	20	Y
1	PC	N	30	0	0	60	4	Y
1	PC	N	60	0	0	60	5	Y
1	PC	N	90	0	0	60	5	Y
1	PC	N	30	75	0	60	5	Y
1	PC	N	0	5	30	0	10	N
1	PC	N	0	10	30	0	41	N
1	PC	N	0	15	30	0	50	N
1	PC	N	0	15	45	0	4	N
1	PC	N	0	5	60	0	5	N
1	PC	N	0	10	60	0	5	N
1	PC	N	0	20	60	0	10	N
1	PC	N	0	45	60	0	8	N
1	PC	N	0	60	90	0	8	N
1	GI	N	0	5	60	0	10	N
1	GI	N	0	15	60	0	10	N
1	GI	N	0	15	90	0	10	N
1	GI	N	0	15	120	0	10	N
1	GI	N	5	15	45	0	8	N
1	GI	N	10	15	60	0	10	N
1	GI	N	20	15	60	0	10	N
1	GI	N	10	10	30	0	10	N
1	GI	N	10	10	60	0	20	N
1	GI	N	15	5	30	0	10	N
1	GI	N	15	5	60	0	10	N
1	GI	N	15	10	60	0	10	N

Table 5. A summary of oyster shucking treatments under Method 2.

Method	Source	Pre-Freeze	Pre-Heat (s)	Steam Injection (s)	Hold (s)	Post-Process Chill (s)	Reps	Banded
2	PC	N	45	30	0	240	15	Y
2	PC	N	30	30	30	240	15	Y
2	PC	N	15	30	60	240	15	Y
2	PC	N	15	30	45	240	8	Y
2	PC	N	15	30	30	240	8	Y
2	PC	N	15	30	45	240	15	Y
2	PC	N	15	45	30	240	15	Y
2	PC	N	15	45	0	240	15	Y
2	PC	N	30	30	0	240	15	Y
2	PC	N	30	45	60	240	7	Y
2	PC	N	60	30	60	240	8	Y
2	PC	N	0	52	90	240	15	Y
2	PC	N	0	45	90	240	15	Y
2	PC	N	0	60	90	240	15	Y
2	PC	N	0	90	60	240	15	Y
2	PC	N	0	120	0	240	15	Y
2	PC	N	0	90	0	240	15	Y
2	PC	N	0	60	60	120	15	Y
2	PC	N	0	120	0	120	7	Y
2	PC	N	0	90	0	120	7	Y
2	PC	N	0	120	0	120	7	Y
2	PC	N	0	90	60	120	7	Y
2	GI	N	0	60	0	120	7	Y
2	TX	N	0	60	60	120	5	N
2	TX	N	0	90	60	120	5	N
2	TX	N	0	120	60	120	5	N
2	TX	N	0	120	60	120	5	N
2	TX	N	0	120	60	120	5	N
2	TX	N	0	90	60	120	5	N
2	PC	N	0	90	60	120	15	N
2	PC	N	0	90	60	120	15	Y
2	PC	N	0	60	60	120	7	Y

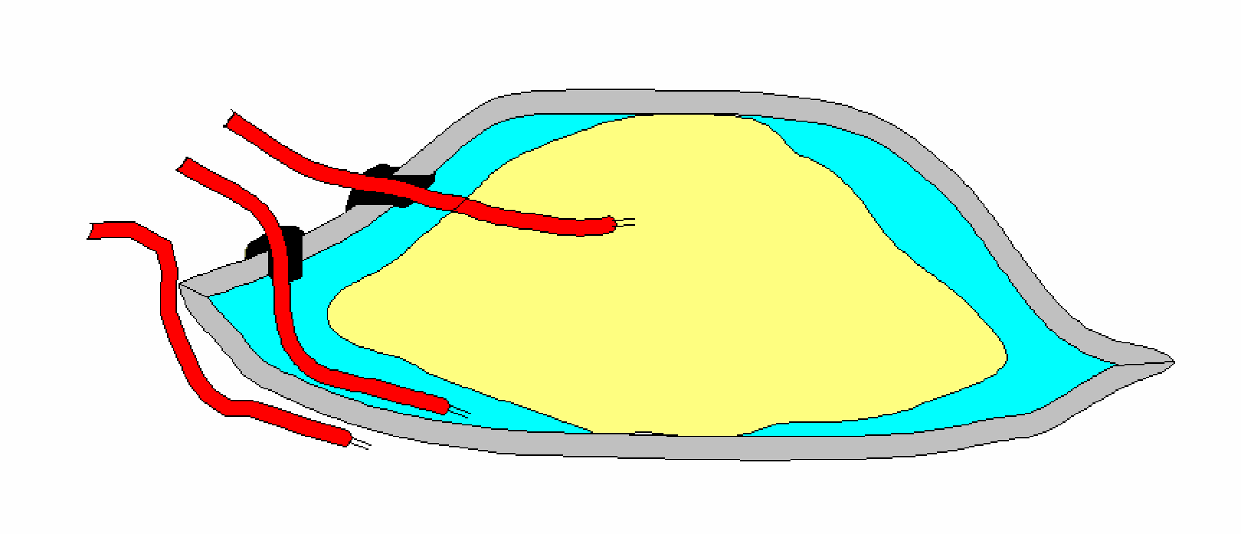


Figure 39. Thermocouple placement within and on an instrumented oyster.

Figure 40. Instrumented oyster with clay plugs.

Results and Discussion

It was initially thought that pre-freezing the oysters prior to steam treatment might cause the adductor muscle of the oysters to release from the shell. For example, a batch of oysters was subjected to pre-freezing via CO_2 to approximately -25°C during the first 300 seconds of the run (Figure 41). Following pre-freezing, a vacuum was pulled on the retort to evacuate the air inside the vessel so the steam could rapidly enter and heat the oysters. After approximately 14 psi vacuum was achieved, steam was injected at 30 psi for 45 seconds. The oysters were then held in the retort for 60 seconds after which time pressure was released by opening the vent valve. The lid was removed from the retort and the oysters were placed on a metal tray and re-subjected to rapid cooling to 0°C in the cryogenic tunnel with CO_2. What can be seen from the graph is that the outside temperature during the pre-freeze fell to -50°C and fluctuated between -45°C and -60°C as the thermostat on the cryogenic tunnel cycled on and off. The temperatures of the inside shell and oyster muscle also fell below 0°C but quickly increased as steam was applied. The muscle temperature lagged behind the inside shell temperature, as would be expected, as the heat would transfer first to the inside of the shell and then into the muscle. At the end of the hold time, the oysters were removed from the retort and rapidly chilled. Unfortunately, the pre-freezing had little to no positive effect on the release of the adductor muscle from the shell.

Since the pre-freeze showed less than desirable results, the next treatment consisted of only steaming the oysters followed by rapid CO_2 chill. This process is illustrated in Figure 42. The oysters were subjected to a 15 second steam treatment followed by a 30 second hold and then rapidly chilled in the cryogenic tunnel with CO_2.

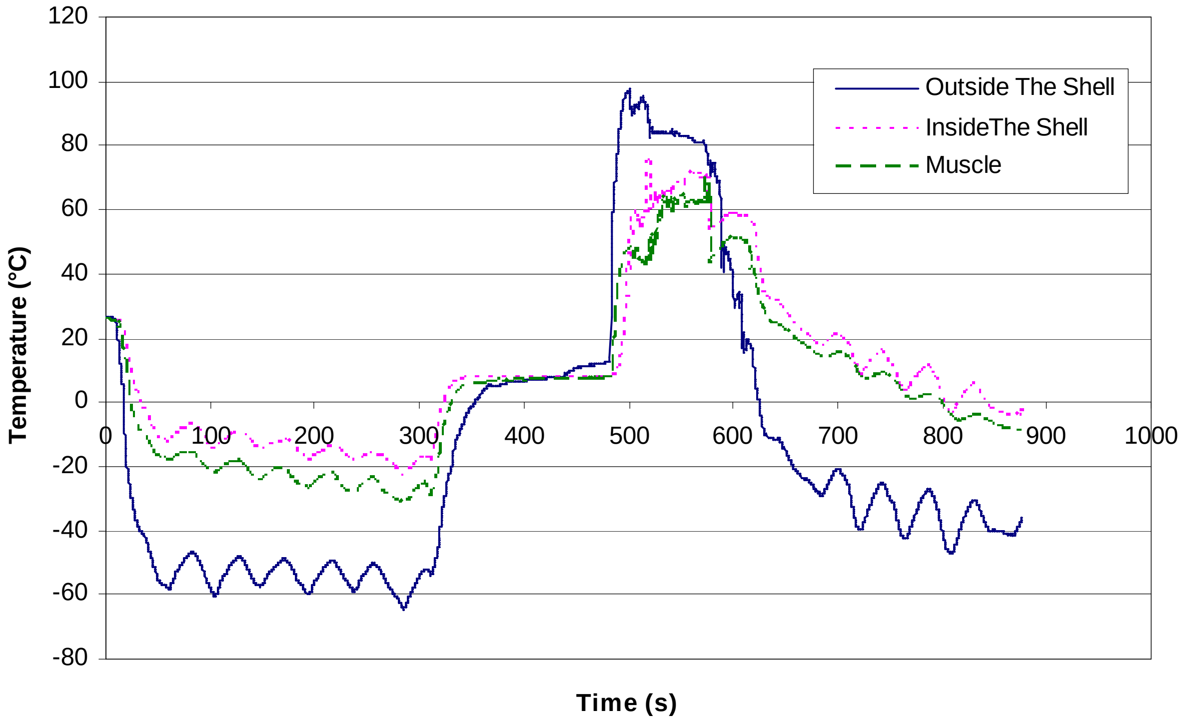


Figure 41. A time-temperature history using Method 1 shows cold, hot and cold temperatures recorded at three locations on and in an oyster. The treatment consisted of cryogenically freezing oysters with CO_2 until the muscle temperature reached -25°C followed by a 45 second steam injection and a 60 second hold. The oysters then were removed from the retort and chilled to 0°C with CO_2.

This treatment resulted in 75% of the oysters exhibiting a full release of the adductor muscle where both the translucent and opaque muscles cleanly released from the shell.

Figure 43 shows how a 15 second pre-heat was used in conjunction with a 5 second steam injection and 30 second hold to treat oysters. In this case, instead of using CO_2 to chill the oysters after treatment, ice water was injected straight into the retort by means of the vacuum pump. This allowed a more rapid cooling following treatment than was possible with the CO_2. In addition, most oyster processors have a ready supply of ice on hand at their operations which would make it a more commercially feasible cooling alternative for small seafood processors. As can be seen from Figure 44, this treatment

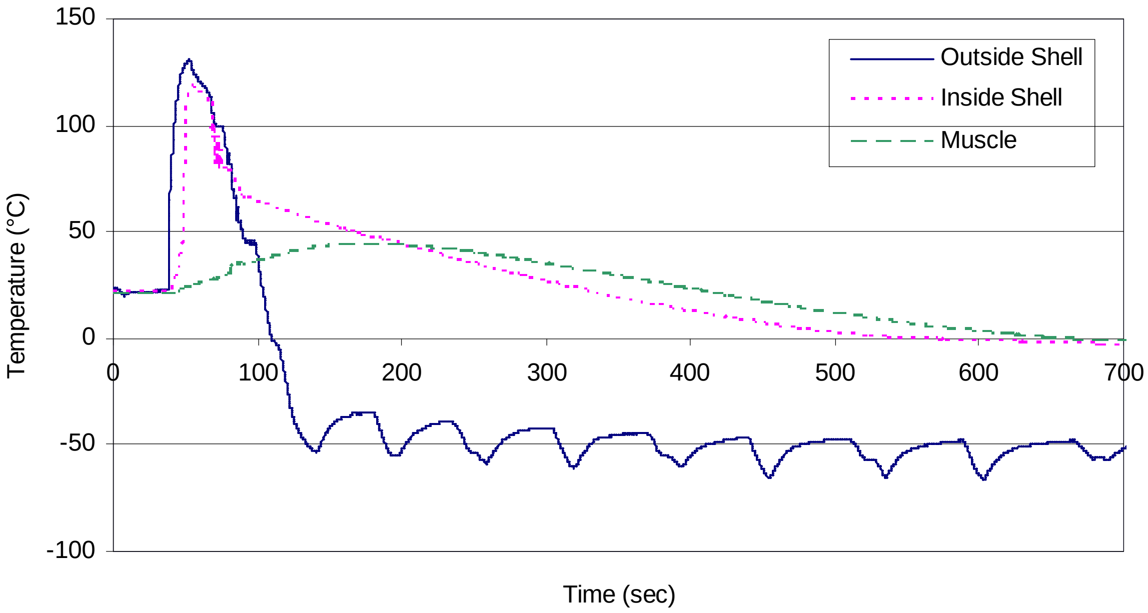


Figure 42. A time-temperature history using Method 1 shows hot and cold temperatures recorded at three locations on and in an oyster. The treatment consisted of a 15 second steam injection and a 30 second hold. The oysters then were removed from the retort and chilled to 0°C with CO_2.

resulted in only 20% of the oysters resulting in a full release and then another 20% giving a partial release where only part of the muscle released, usually the translucent muscle but not the opaque. Figure 44 also shows the rest of the treatments that were conducted under Method 1. From this graph it can be seen that some of the treatments resulted in up to 90% release when combining both full and partial releases. When these tests were run, the quality of the oyster meat was not recorded as the initial objective was to successfully achieve shucking. It became apparent, though, that good oyster quality after treatment was going to be essential to a successful operation. As a result, Method 2 incorporated an indicator of quality in the overall evaluation of each treatment.

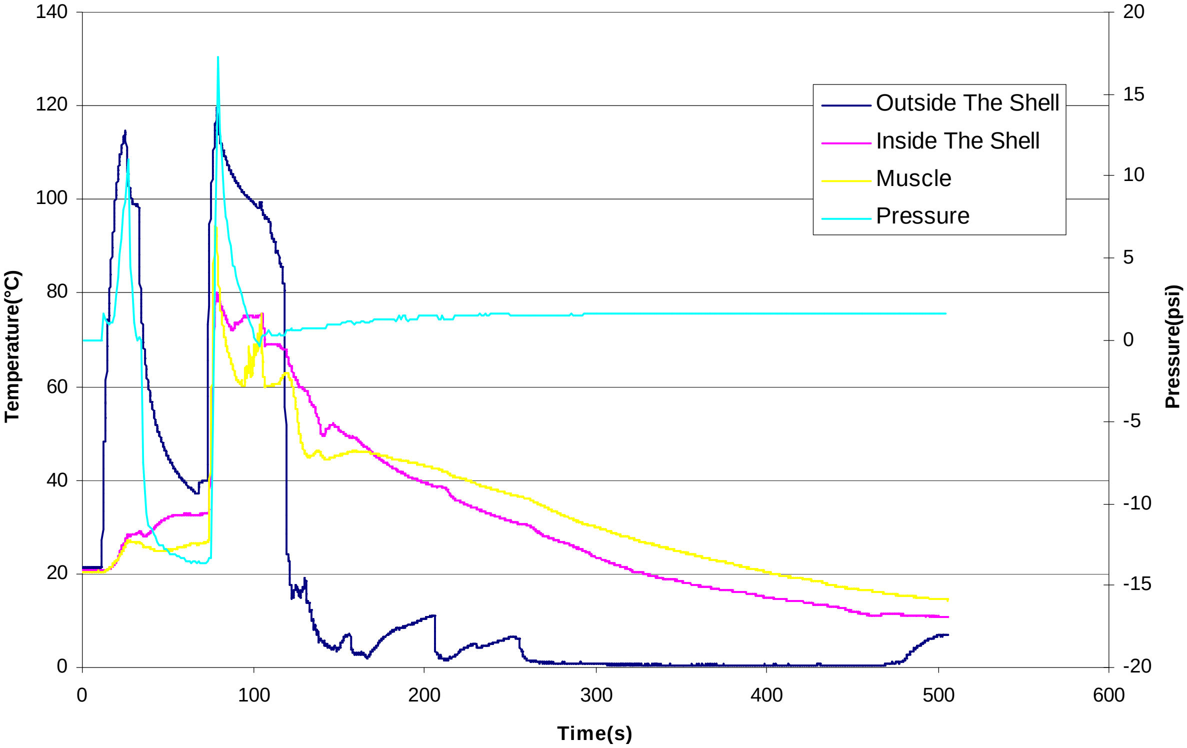


Figure 43. Thermal oyster shucking process graph under Method 1. Treatment consisted of a 15 second pre-heat, 5 second steam injection and a 30 second hold followed by ice water bath post-process chill.

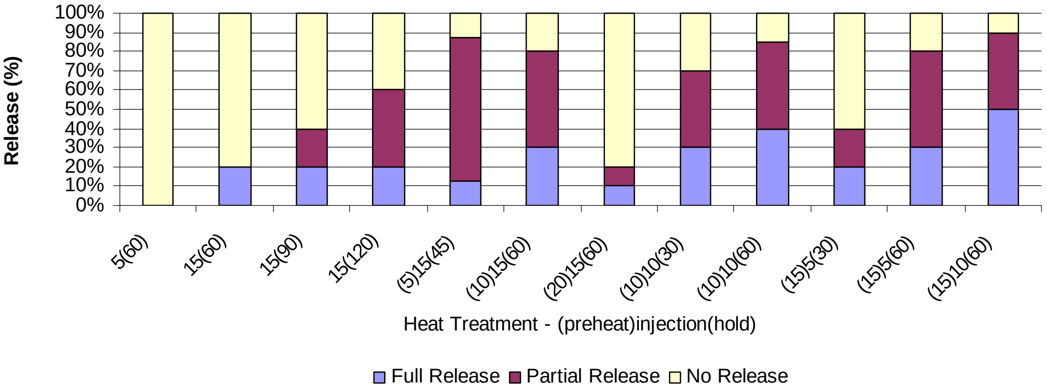


Figure 44. Summary of releases for oyster shucking treatments under Method 1.

Figure 45 shows a typical treatment under Method 2. Under Method 2, a steam generator supplied steam to the system at pressures ranging from 30-60 psi and the cryogenic tunnel was not used to pre-freeze or post-chill. The treatment for Figure 5 consisted of 30 seconds of pre-heat in the same manner as Method 1, 30 seconds of steam injection, 30 seconds of hold time and then 4 minutes of post-process chill by injecting ice water into the retort. Under Method 2, relaxation, muscle release of both the opaque and translucent muscles for both the left and right valve and meat quality were quantified. So instead of reporting full, partial or no release, each oyster had a quantitative measure of how it responded to the treatment. Degree of release was determined by carefully prying the shells of the oyster open and observing how much of the adductor muscle, both opaque and translucent, remained attached to the muscle scar. If the scar was completely free of any muscle, a value of zero was given. If either type of muscle was still attached, a value ranging from 1.0 to 3.0 was assigned. A value of 3.0 indicated that no muscle release was achieved. Degree of release was recorded for both opaque and translucent muscle types for both left and right valves. After this particular treatment, the oyster ended up cooked as can be seen from the resulting quality of Oyster A (3.0) in the data sheet in Figure 46. Oysters D, E, G, and H responded very well to the treatment as can be seen in the resulting Quality Values of less than or equal to 2.0. The Average Release Value (ARV) also must be less than or equal to 1.0. The ARV is the average of the release value of each of the valves of the oyster for each of the muscle types. An ARV of zero would indicate that both muscles released cleanly from both shells. A summary of the oysters that responded successfully to the treatments is listed in Table 3.

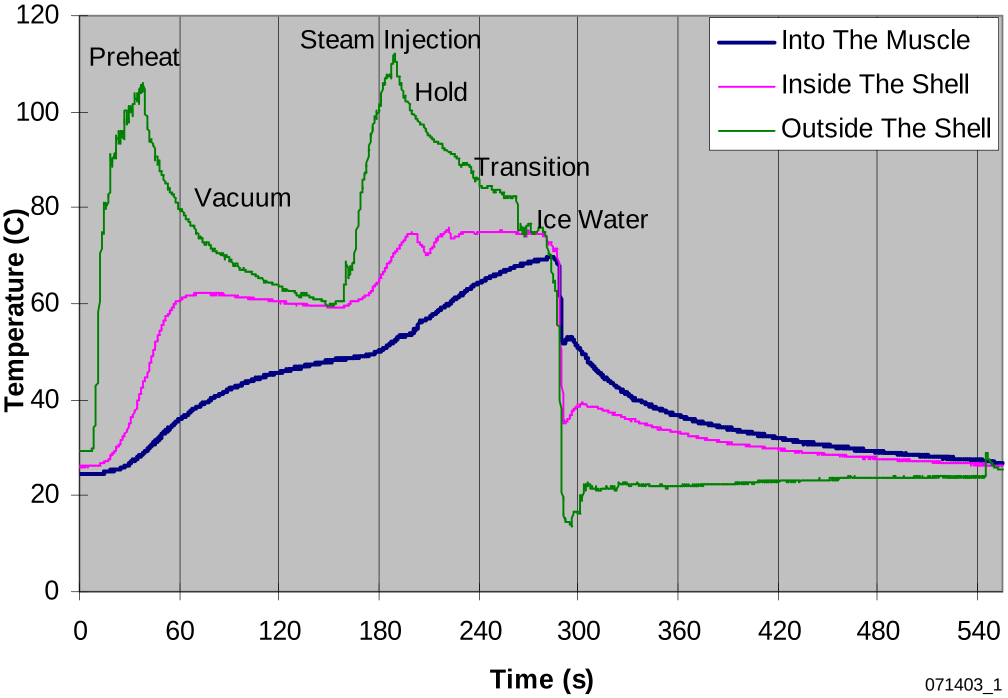
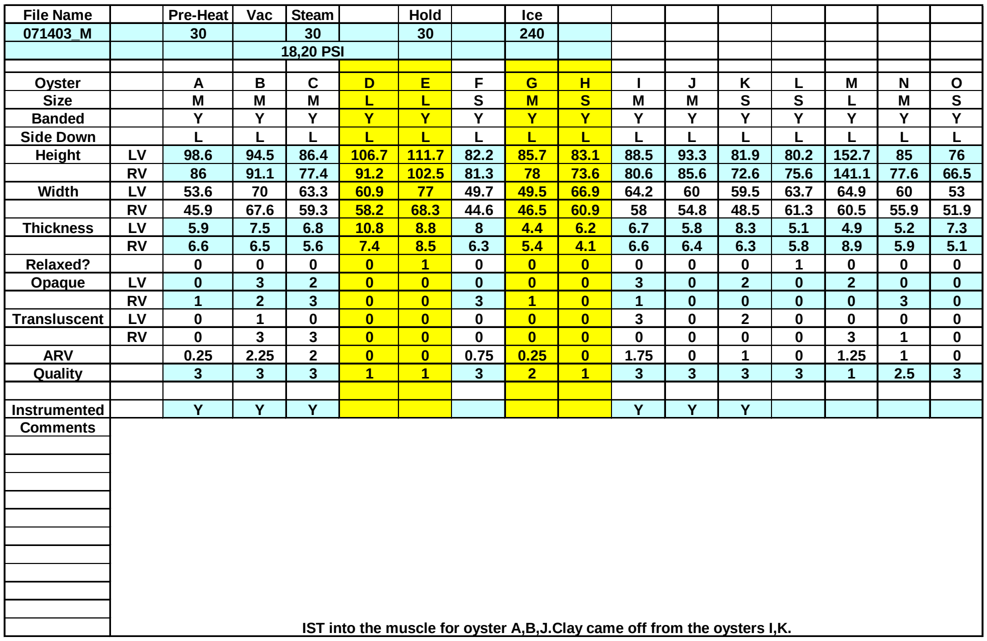


Figure 45. Typical thermal response of Louisiana Gulf Coast oysters (*Crassostrea virginica*) to pre-heat, steam injection, hold and ice water chill.



File Name		Pre-Heat	Vac	Steam		Hold		Ice								
071403_M		30		30		30		240								
				18,20 PSI												
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Size		M	M	M	L	L	S	M	S	M	M	S	S	L	M	S
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	98.6	94.5	86.4	106.7	111.7	82.2	85.7	83.1	88.5	93.3	81.9	80.2	152.7	85	76
	RV	86	91.1	77.4	91.2	102.5	81.3	78	73.6	80.6	85.6	72.6	75.6	141.1	77.6	66.5
Width	LV	53.6	70	63.3	60.9	77	49.7	49.5	66.9	64.2	60	59.5	63.7	64.9	60	53
	RV	45.9	67.6	59.3	58.2	68.3	44.6	46.5	60.9	58	54.8	48.5	61.3	60.5	55.9	51.9
Thickness	LV	5.9	7.5	6.8	10.8	8.8	8	4.4	6.2	6.7	5.8	8.3	5.1	4.9	5.2	7.3
	RV	6.6	6.5	5.6	7.4	8.5	6.3	5.4	4.1	6.6	6.4	6.3	5.8	8.9	5.9	5.1
Relaxed?		0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Opaque	LV	0	3	2	0	0	0	0	0	3	0	2	0	2	0	0
	RV	1	2	3	0	0	3	1	0	1	0	0	0	0	3	0
Transluscent	LV	0	1	0	0	0	0	0	0	3	0	2	0	0	0	0
	RV	0	3	3	0	0	0	0	0	0	0	0	0	3	1	0
ARV		0.25	2.25	2	0	0	0.75	0.25	0	1.75	0	1	0	1.25	1	0
Quality		3	3	3	1	1	3	2	1	3	3	3	3	1	2.5	3
Instrumented		Y	Y	Y						Y	Y	Y				
Comments	IST into the muscle for oyster A,B,J.Clay came off from the oysters I,K.															

Figure 46. Data sheet for automated oyster shucking study. Highlighted columns indicate oysters that were successfully shucked.

Summary and Conclusions

From these studies, it was determined that gulf oysters can be treated to cause a relaxation of the adductor muscle which facilitates the shucking process. Several of these treatments caused a full or partial release of the adductor muscle in 75% or more of the oysters. Further study would allow for a more comprehensive investigation into the treatment combinations that have already shown promise. This methodology could be applied to oysters from other sources or other species for similar tests. This information potentially could be used to commercialize the process.

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Chapter 6. A Comparison of Current, Commercial Gulf of Mexico Oyster Processing Technologies for the Production of Raw or Nearly-Raw Oysters

Introduction

The Gulf of Mexico produces some of the finest oysters in the world that are enjoyed in a variety of ways. Raw oysters are considered by connoisseurs to be a particular delicacy. Raw oysters are traditionally served on the half shell, where the oysters are shucked and served raw in the shell, typically at restaurants and oyster bars. Some other ways that people enjoy oysters are fried, baked, or cooked in stews and soups. These preparations begin with raw oysters that have been shucked or removed from the shell. Processes produce both oysters for the half shell (fresh) market as well as containers of the shucked meat, which is primarily intended for cooking before consumption.

Oyster Biology and Physiology

Oysters are bivalve mollusks that have two calcareous shells that enclose and protect the oyster. The oyster is secured to the shells on the inside by means of an adductor muscle that is fixed to both the upper and lower shells, commonly referred to as the left and right valve (Figure 47). At the anterior region is the beak or hinge of the oyster that contains a resilient lamellar ligament that counteracts the motion of the valves. When the oyster opens to feed, the ligament is compressed. When the oyster closes its valves, the ligament is tensed. When shucking an oyster, the valves must be pried apart and the adductor muscle must be severed from the inside of the shell on both the left and right valves.

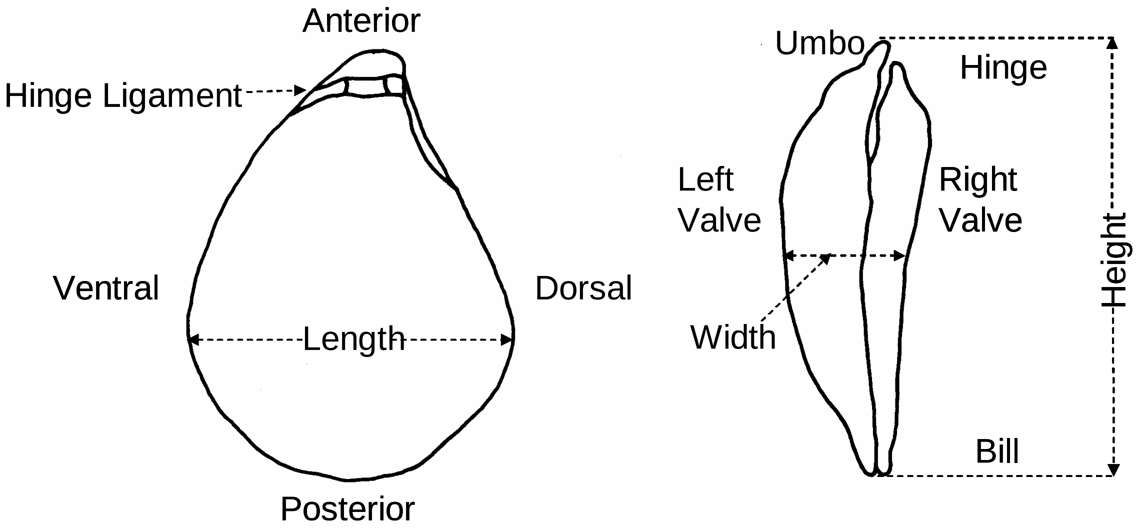

Figure 47. Diagram depicting anatomical features and the height, width and length of an oyster.

Literature Review

Many methods have been investigated to achieve shucking. One of the earliest was the use of a hammer to break the bill or the hinge, followed by the insertion of a knife to pry open the shells. In the mid-1800's, the commonly used oyster knife was invented that had a blade rigid enough to pry open the shells and sever the adductor muscle (Blake, 1854). In the late 1800's, many different tools were invented to facilitate this process, many being modifications to the oyster knife and others using the mechanical advantage of a lever attached to a wedge of various sorts to separate the shells (Towers, 1854; Seipel and Rupp, 1858; Hawkins, 1862; Huffnagle, 1868; Pattberger, 1869; Boyer, 1871; Holtzmann, 1871; Starin, 1872; Berger, 1874; Megee, 1874; Lum and Sanford, 1876; Temple, 1877; Heimlich, 1878; Leduc, 1885; De Lamarre, 1888; Steuart, 1889). In the early to late 1900's, various multi-function machines were invented to not only shuck oysters, but also to separate the shells from the detached meat (Torsch and Parker, 1907; Egli, 1923; Doxsee and Cook, 1935; Jenkins, 1936). Most of these were mechanical in nature, but many of the later methods incorporated the use of dry heat, infrared radiation, microwave energy, steam, and lasers (Doxsee and Cook, 1935; Jenkins, 1936; Cook, 1937; Paparella and Allen, 1970; Nelson, Mackin et al., 1971; Spracklin, 1971; Wheaton, 1971; Snow, 1971a; Taylor, 1983). While many of these methods were successful in shucking oysters, few ever became commercially viable. The mechanical methods tended to be cumbersome and did not offer an appreciable advantage over a skilled shucker. Many of the heating methods, although acceptable for canning operations, tended to change the taste, texture and appearance of the oysters. Those heating methods that did produce acceptable quality meats were too expensive for commercial operation.

In the early 1970's, concern arose about the potential health hazard that the consumption of oysters posed to certain at-risk groups. The primary pathogen of concern was *Vibrio vulnificus*, which is a naturally occurring bacterium in marine waters. It is typically more abundant in warm water than cold and its presence or lack thereof, is not an indication of water quality. By law, oysters only may be harvested from approved waters because many are consumed raw. Although harmless to most individuals, *V. vulnificus* can, if present in sufficient numbers, cause extreme adverse reactions, including death, in certain at-risk individuals. These individuals include those who have weak immune systems as well as those who have liver damage. *V. vulnificus* may enter the body through a break in the skin or by ingestion of raw food. However, *V. vulnificus* is destroyed by cooking. Since oysters are often consumed raw, raw oysters are a possible vector for ingestion of this pathogen. Therefore, some recent processing methods have included the reduction of *V. vulnificus* as one of their objectives to increase food safety. Two of these methods are in commercial operation and will be further discussed in detail.

High pressure processing (HPP) is probably the most versatile of the new technologies. This technology can be used to shuck oysters or to shuck the oysters and treat them for the possible presence of *V. vulnificus*. Both processes are similar, differing primarily in the time of application of pressure. The pressure is applied by fully immersing the oysters in liquid (water) and pressurizing the water. Typical commercial pressures range from 35,000 to 40,000 psi although pressures outside of this range may be employed. These pressures are sufficient to break down the protein layer, which bonds the adductor muscle to the shell. This is accomplished within one minute, resulting in oyster meat which is detached from the shell and which is otherwise nearly indistinguishable from raw, untreated meat. Longer applications of pressure, in the neighborhood of three minutes, provide for the elimination of *V. vulnificus* that may be present in the raw oyster, to non-detectable levels.

At least two commercial establishments, both located in Louisiana, are currently using the HPP process. They are Motivatit Seafood of Houma, the originator of the process and holder of the patent for the process (Voisin, 2003), and Joey Oyster of Amite.

Traditional Oyster Shucking

The employment of manual shuckers is by far the most common commercial processing method for raw or nearly-raw Gulf of Mexico oysters. In this process individuals open the oyster shell and remove the meat manually. One of two techniques is usually employed. Some shuckers open the oyster by forcing their oyster knife between the two halves of the oyster's shell at the bill of the oyster, and once inserted, twisting the knife to force the shell open (Figure 48). The knife is then inserted and the meat detached from one half shell which is discarded, allowing free access to separate the meat from the remaining half shell. The oyster meat is temporarily stored in the shucker's container until such time that the meat is collected for washing, chilling and further packaging for sale. The second technique is similar, differing only in that the shucker forces the oyster knife into the oyster at the hinge rather than at the bill (Figure 49). A hammer may be used to chip the oyster shells at the point of insertion in either of the two techniques. This chipping of the shell makes it easier to insert the knife between the two halves of the shell. Commercially, only the more experienced shuckers with sufficient strength open oysters without first chipping the shells.

An advantage of the manual shucking process is that it requires relatively little capital investment. One good example is the operation at Carlos Oysters in Amite, Louisiana. The shuckers are provided with a station to which whole, live oysters are delivered from refrigerated storage. Each station has an area suitable for placing the oyster while chipping the shell. This may be a built-in metal insert, or a simple metal jig (such as a piece of channel iron), which facilitates holding of the oyster while striking it with the hammer. In addition, a container for the oyster meat and a means of disposing of the empty shells is provided for each shucker. The discarded shells are later collected and sold.

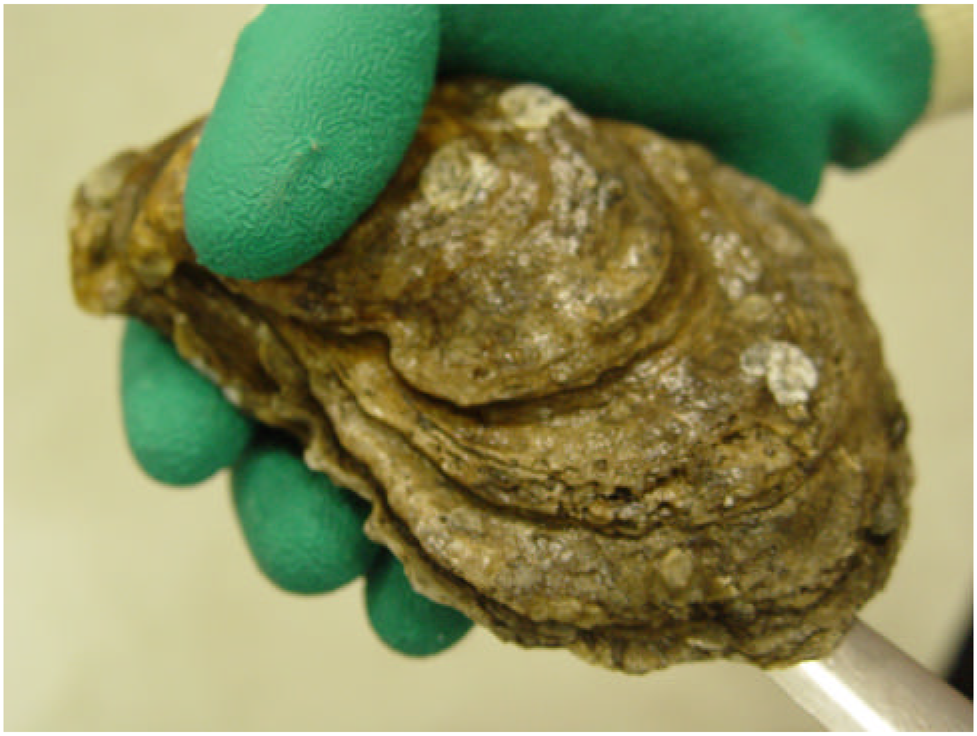

Figure 48. Manual shucking method using traditional oyster knife inserted in the bill.

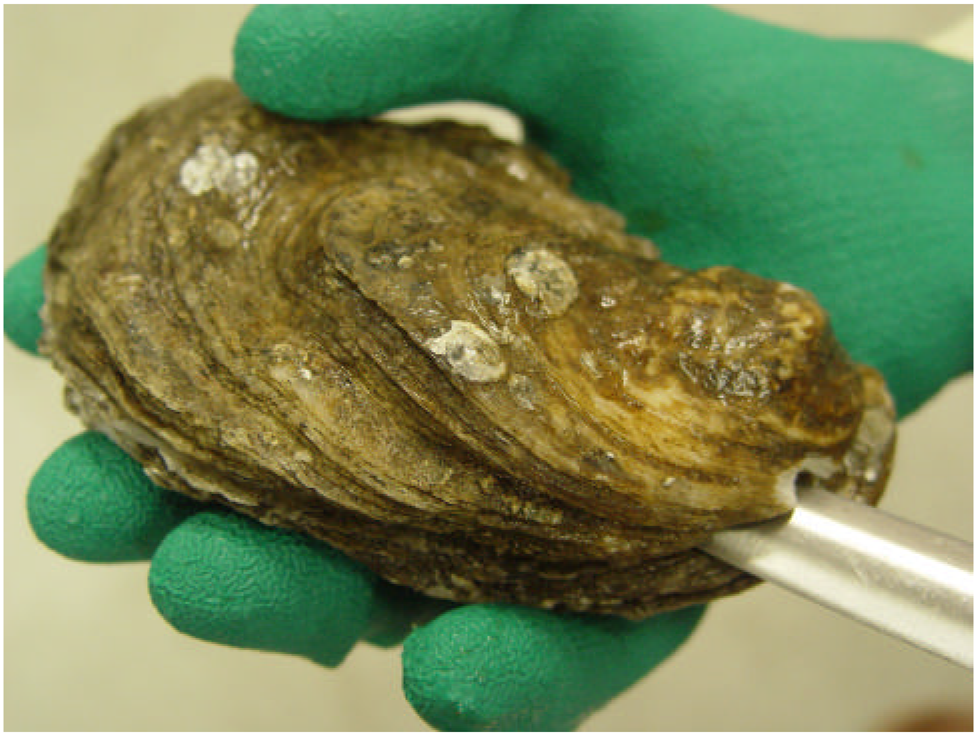

Figure 49. Manual shucking method using traditional oyster knife inserted in the hinge.

A particular disadvantage of this processing technique is the difficulty of employing skilled shuckers. Skilled shuckers are able to remove the meat with little or no damage to the meat. Unskilled shucking, on the other hand, could result in considerable meat left attached to the shell, and an oyster that is cut or torn is thus prone to loose moisture and therefore, weight. Both are undesirable from the standpoint of appearance, quality and yield. An additional factor affecting the yield of a sack of oysters is the tendency for some shuckers (particularly the less skilled and slower shuckers) to discard small oysters or oysters whose shell configuration would make them difficult to open. This tendency may arise, in part, because shuckers are typically paid on a piecework basis – the more oyster meat they shuck, the more money they earn.

High Pressure Processing at Motivatit Seafood

At Motivatit Seafood, oysters that are received from the boats are either stored overnight in cold storage or proceed directly to the processing operation (Figure 50). The oysters, still in the shell, receive a polishing wash in a rotating cylinder (Figure 51) and are then graded for size and appearance (Figure 52). Those oysters meeting the size and appearance for the half shell market are sorted and reserved for the banding line. The rest of the oysters are sent to the shucking line.

The oysters entering the shucking line are placed on conveyors which elevate them and drop them into an open cylindrical container (Figure 53). The container is approximately four feet tall and has a capacity of 45 liters. When the container is full, it is filled with water, capped, and wheeled to the high pressure unit.

Figure 50. Oysters at Motivatit Seafood held in cold storage prior to processing.

Figure 51. Rotating cylinder for cleaning and washing oysters prior to sorting and grading.

Figure 52. Grading and sorting of oysters at Motivatit Seafood.

The high pressure vessel is manufactured by Azure Technologies (Kent, Washington) and has two equal sized chambers (Figure 54). Units of varying capacities are available from the manufacturer. Motivatit has two vessels, each with two 45 liter chambers, large enough for about sixty pounds of oysters per chamber. The chambers are pressurized alternately with only one chamber being under pressure at a time. At the vessel, the containers are hoisted by an electric winch and placed in the chamber (Figure 55). The chamber is closed and pressure is applied for approximately one minute. The pressure is released, the chamber opened, and the containers removed. The container is transported to the shucking tables where it is opened and the oysters are delivered to the shuckers (Figure 56). The oysters are already separated from the shell but the slightly open shell must occasionally be pried completely open with a knife to let the oysters slide out. The two vessels combined are able to process approximately 1,800 pounds or 18-100 lb. sacks of in-shell oysters per hour.

Figure 53. Oysters conveyed into cylindrical containers prior to pressurization.

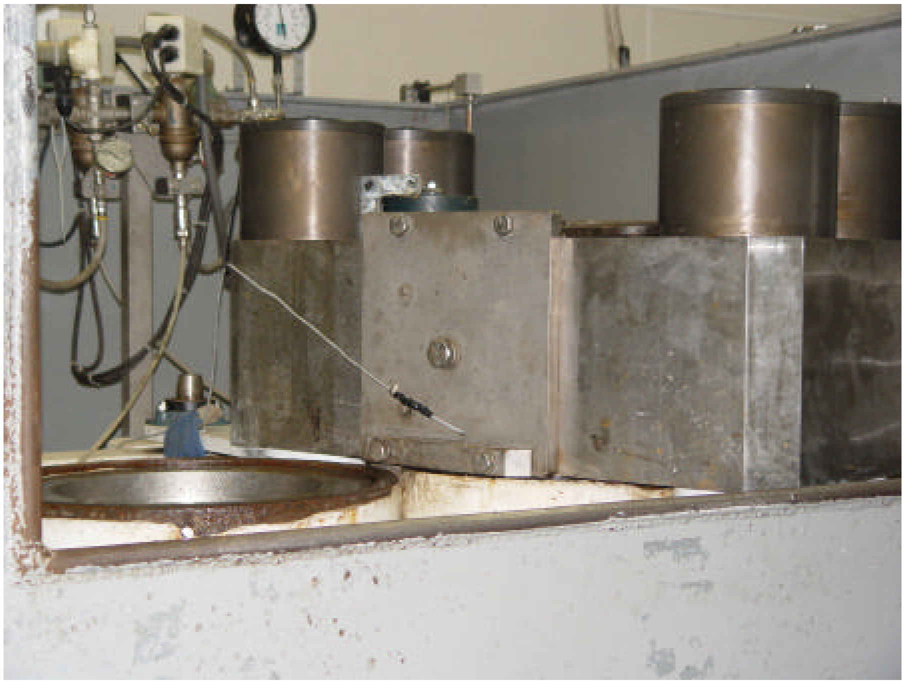

Figure 54. Closeup of high pressure vessel with two separate chambers for shucking oysters.

Figure 55. Cylinder of oysters being loaded into high pressure vessel at Motivatit Seafood.

Figure 56. Shucked oysters being delivered to shucking table for meat separation from the shell.

The shucked oysters are placed in a water sluice and the oyster shells are discarded for collection (Figure 57). The shucked oyster meats flow along the sluice to the wash station where they are further washed of any remaining pieces of shell in a cascading water bath (Figure 58). The washed oysters are placed in shallow plastic containers, refrigerated and stored for further packaging and sale (Figure 59).

This process results in very attractive oyster meat which has not been damaged by the shucking process. It also produces a better yield because there is no cutting or tearing of the oyster which results in less moisture loss as well as no loss of meat remaining

Figure 57. Shucked oysters being deposited into a water sluice for further washing.

Figure 58. Shucked oysters traveling down sluice into cascading wash basin.

Figure 59. Shallow plastic containers used to hold and store shucked oysters prior to packaging.

attached to the shell. The increase in yield compared with conventionally shucked oysters will vary and depends upon the season and the skill of the traditional oyster shucker. Motivatit reports increased yields of up to 60%, but more typically in the 20% range: regardless, the yield increase is judged sufficient to justify use of the technique. The HPP process, as with the other post-harvest techniques, results in an oyster which is no longer alive. Since the process also kills spoilage microorganisms, shucked oysters treated with HPP are reported to have an increase in shelf life from one to three weeks.

Oysters for the Half-Shell Market

Those oysters selected for the half-shell market enter the banding line after washing and sorting. This process is similar to the previously described process except that the oysters are banded prior to the high pressure treatment, the high pressure is applied longer and the oysters remain in the banded shell after processing and are sold in that form.

In the banding process, one worker places an oyster onto a custom conveyor belt which holds the oyster in a vertical position. A second worker places a heat-shrinkable gold-colored band over the oyster (Figure 60). The oyster, still on the conveyor belt, passes through a series of heat guns which shrink the band (Figure 61). The oyster is then conveyed to and loaded into the cylindrical containers for pressurization. The pressurization process is the same as previously described except that the pressure is applied for approximately three minutes. This longer process time is not necessary to shuck the oyster but is used to reduce *V. vulnificus* to non-detectable levels. Following the pressure treatment, the oysters are packed, chilled and kept in cold storage until sale. The shucking operation at Motivatit is graphically depicted in Figure 62.

Figure 60. Banding of oysters prior to high pressure processing.

Figure 61. Heat guns used to shrink wrap heat-sensitive band around oysters.

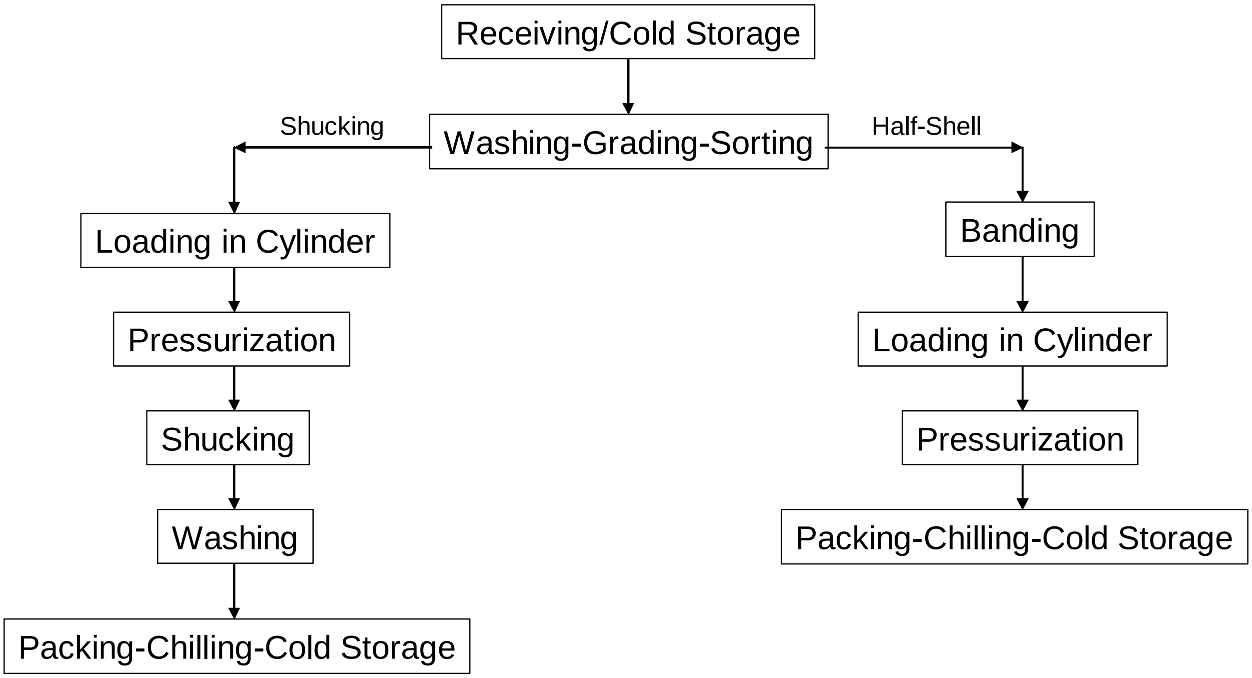

Figure 62. Schematic for oyster processing at Motivatit Seafood, Inc.

High Pressure Processing at Joey Oyster

Joey Oyster of Amite, Louisiana also utilizes the high pressure process. They produce a shucked oyster which has been processed for sufficient time and pressure to reduce *V. vulnificus* to a non-detectable level. This is accomplished by holding the pressure for approximately two minutes. A full cycle requires about seven minutes to complete. They also use a single cylindrical container with a capacity of 215 liters which can hold approximately three sacks of oysters, or about 300 pounds (Figure 63). This results in about a 2,500 pound per hour capacity.

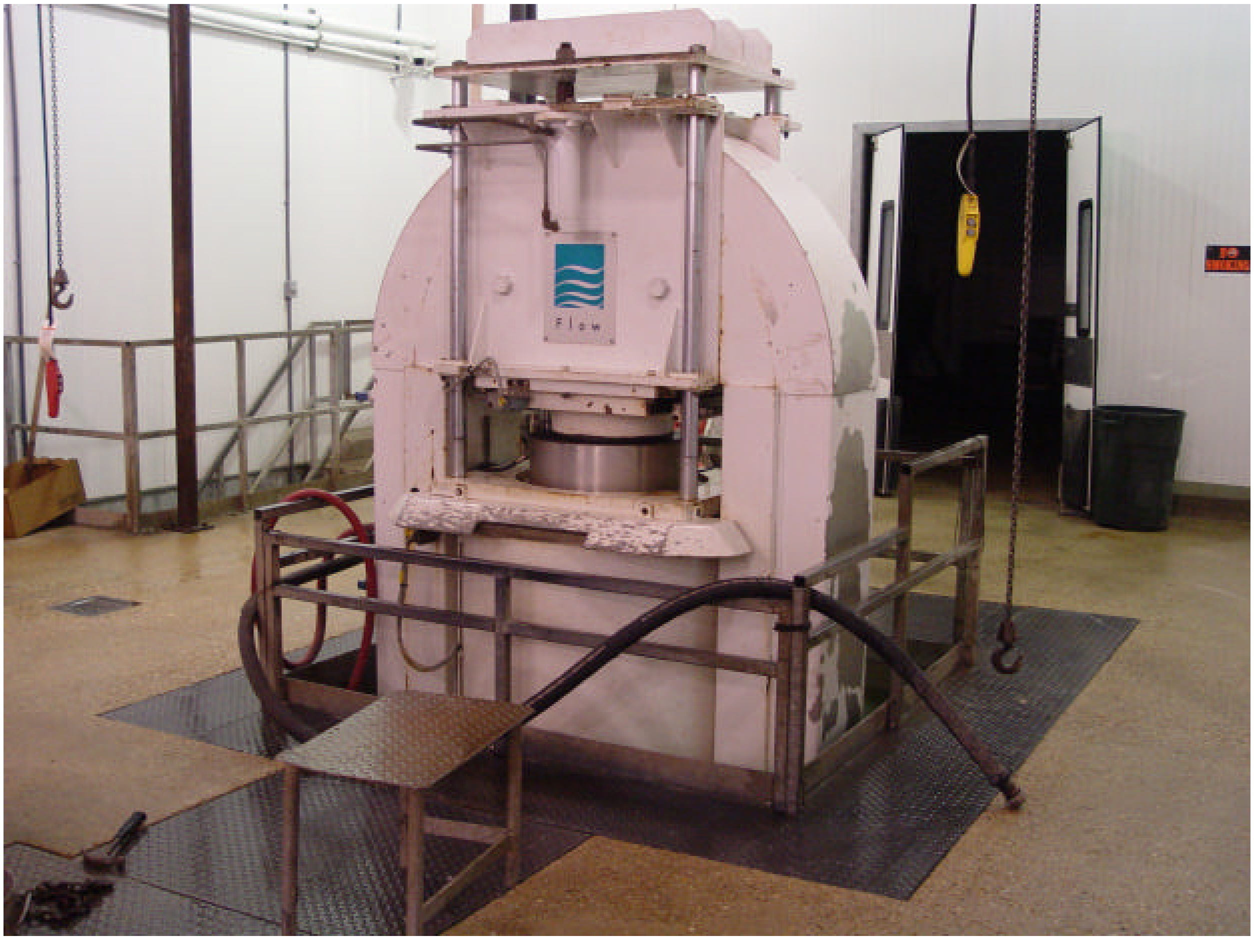

Figure 63. High pressure processing vessel at Joey Oyster.

Another difference in the two HPP operations is that Joey Oyster holds the HPP treated oysters in cold storage until enough have accumulated for removal of the meat from the shell. The shuckers may receive oysters that are sufficiently gaped that the oyster meat just slides out. If not, a knife is used to further open the shell, a procedure that is much easier than with an untreated oyster. Joey Oyster does not notice the significant increase in yield that Motivatit reports, perhaps because of the longer pressure application time or because of differences in the skill levels of the manual shuckers; however, they feel that the ease of shucking is a major benefit of the process. Following shucking, the oysters are placed in shallow plastic containers, refrigerated and stored for further packaging and sale.

Oyster Pasteurization at Ameripure, Inc.

Another technology currently employed for oyster processing is pasteurization. Although this process does not shuck the oyster, it does reduce the level of *V. vulnificus* to non-detectable levels without cooking the oyster. This process was patented by Ameripure, Inc. in 1998 (Tesvich, Schegan et al.). In this process, oysters are brought in, washed, sorted according to size and graded based on appearance. The better looking oysters are separated for the half shell market and banded with a rubber band to prevent the oysters from opening during the pasteurization process. After separation, the oysters are placed in plastic trays, several of which are then fitted into a metal frame that is immersed into a bath of water between 49-55°C. The oysters are held in this bath for 10-45 minutes depending on the size of the oysters, the temperature of the water and the initial temperature of the oyster meat within the shell (Figure 64). Following mild heat treatment, the oysters are transferred in the metal rack/frame structure to a chilled water tank (40°F) for 15 minutes to bring the internal temperature of the oysters below 7°C. The unbanded oysters are transferred to a separate line for shucking. Whether the oysters are intended for the half-shell market or for shucking, all are pasteurized. The oysters for the half-shell market are not shucked but the others are then manually shucked, iced down, and held for further packaging and sale.

Figure 64. Banded oysters being immersed in warm water bath at Ameripure, Inc. to virtually eliminate *Vibrio vulnificus*.

Summary and Conclusions

Currently, the traditional oyster processing method utilizing manual hand shucking dominates the industry. This processing method, while having relatively low capital costs, is dependent on the availability of skilled shuckers. Because of concern of potential health effects due to *V. vulnificus* and because of the difficulty of finding skilled shuckers, the industry has investigated new techniques for commercial processing. Current commercial techniques include high pressure processing, low temperature pasteurization and cryogenic freezing. All of the newer processing methods require higher capital costs than the traditional hand shucking method.

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Chapter 7. Summary and Conclusions

Instrumentation techniques were developed to measure temperature both within and adjacent to live oysters and to record those temperature readings on a datalogger. Equipment was designed and set up to thermally shuck oysters via steam and rapidly cool them with nitrogen, carbon dioxide or ice water following treatment. Methods were established for determining and quantifying the ability of the shucking treatments to effect oyster relaxation and muscle release, as well as the resulting affects on meat quality. The effects of the thermal shucking treatments on microbial flora also were quantified over a storage period of 14 days. Methods also were successfully established for determining textural changes in oysters as a result of processing. Future work might include running *Vibrio* specific tests for microbial analysis and using a shear test for the textural analysis to simulate chewing.

From these studies, it was determined that gulf oysters can be treated to cause a relaxation of the adductor muscle which facilitates the shucking process. Several of these treatments caused a full or partial release of the adductor muscle in 75% or more of the oysters. In particular, a 60 second steam injection followed by a 60 second hold time and 120 seconds of ice water bath (Treatment A in Chapter 4) proved exceptional overall with an overall Average Release Value of 1.18 and an overall Quality of 1.86, both of which are good. Treatment G (from Chapter 4) consisted of a 15 second pre-heat followed by a 45 steam injection, no hold time and 4 minutes of ice water bath. This treatment resulted in an overall Average Release Value of 0.33, which is excellent, and an overall Quality of 2.10 which is very close to acceptable. Sixty-seven percent of the oysters subjected to

Treatment G were considered successfully shucked based on degree of release and quality. Further study would allow for a more comprehensive investigation into the treatment combinations that have already shown promise.

Commercialization of a continuous steam-based shucking operation with operating variables similar to those in this study may have equipment set up like that shown in Figure 5 where culled and graded oysters would be delivered on a conveyor belt to an enclosed, low pressure, pressurized steam chamber. The oysters would fall into a rotary valve which would incrementally load the conveyor belt in the steam chamber with oysters while maintaining a pressure seal. The residence time on the belt in the steam chamber would be adjustable as needed. After steam treatment, the oysters would be dumped into an ice water bath, with mixing as needed to increase heat transfer, for cool-down and then on to a processing table for separation of the meat from the shells.

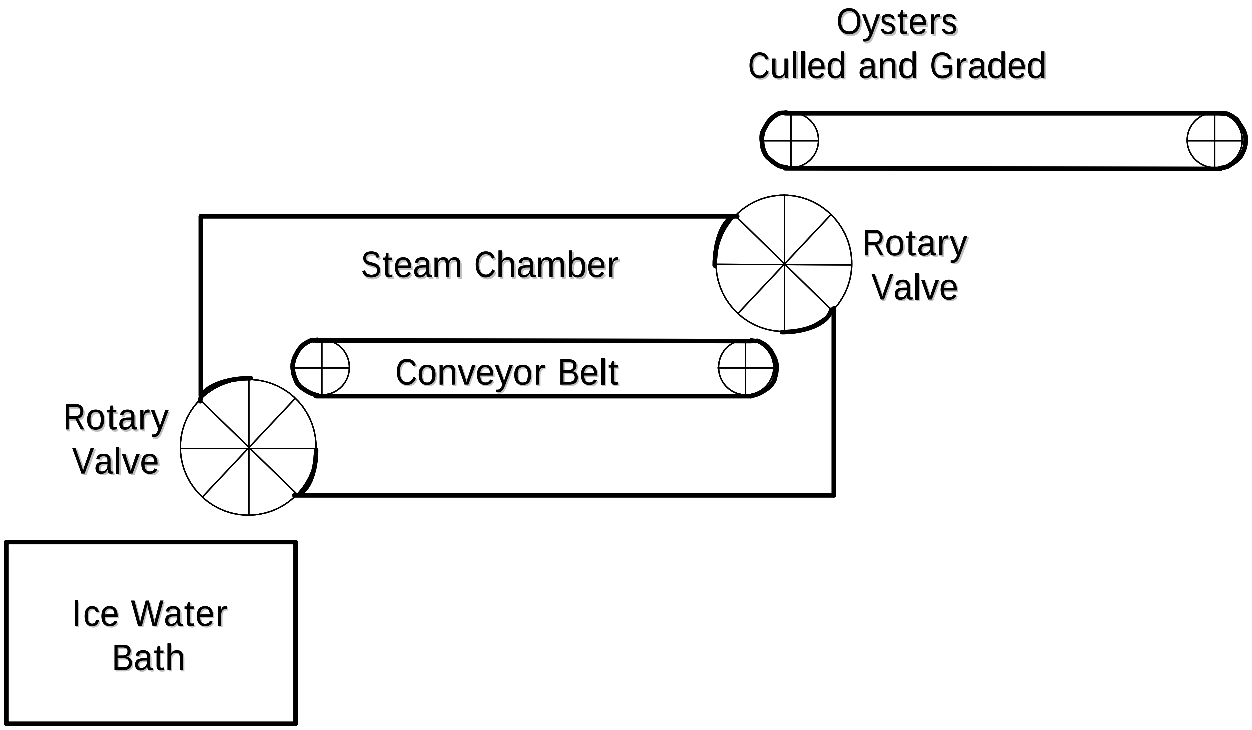


Figure 65. Conceptualization of a commercial steam-based oyster shucking process.

Spoilage bacteria can dramatically reduce the shelf-life of raw oysters. Processes have been developed to control, reduce and eliminate spoilage bacteria from oysters. A couple of these processes are in commercial operation and have been successful in extending the shelf-life of oysters from one week to up to three weeks.

The research from this study has quantified the effect of several mild steam shucking treatments on the levels of bacteria in oysters over 14 days of storage. For some of the treatments, total plate counts for the treated oysters remained below the controls for the entire storage period. Other treatments showed the opposite trend, with treatments resulting in increased total plate counts over the controls. Many of the treatments, however, varied little from the controls and showed no overall effect on the levels of bacteria in the oysters over the two weeks of storage.

Treatments A and E, in particular, resulted in overall improved shelf life over the controls for the duration of the study. From Table 3, it can be seen that overall Treatment A had good releases (ARV=1.18), resulted in acceptable quality (Quality=1.86) and 40 percent of the oysters from that particular treatment met both the qualifications for success (ARV=1.0, Quality=2.0). In contrast, although Treatment E caused bacteria levels to decline during storage compared to the controls, the overall resulting quality of the oysters was poor (Quality=2.67). This treatment caused a cooking of the oysters and would be commercially unacceptable.

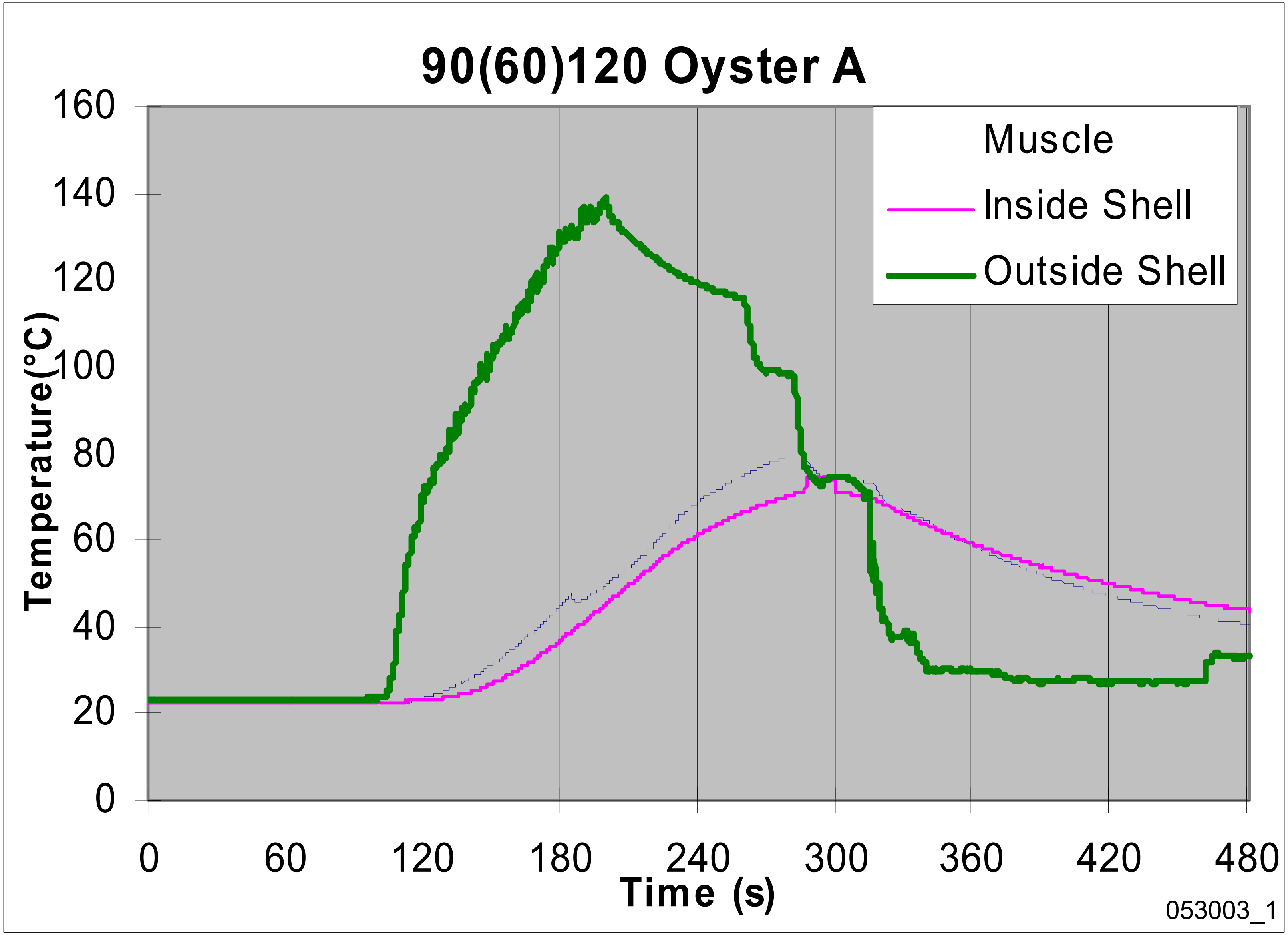
Equally important is to understand which treatments resulted in reduced shelf life of the oysters. Over the 14 days of storage, Treatment H consistently resulted in higher levels of bacteria in the treated oysters versus the controls. In addition, after 10 days of storage, Treatments L and K resulted in bacteria levels greater than two orders of magnitude higher than the controls.

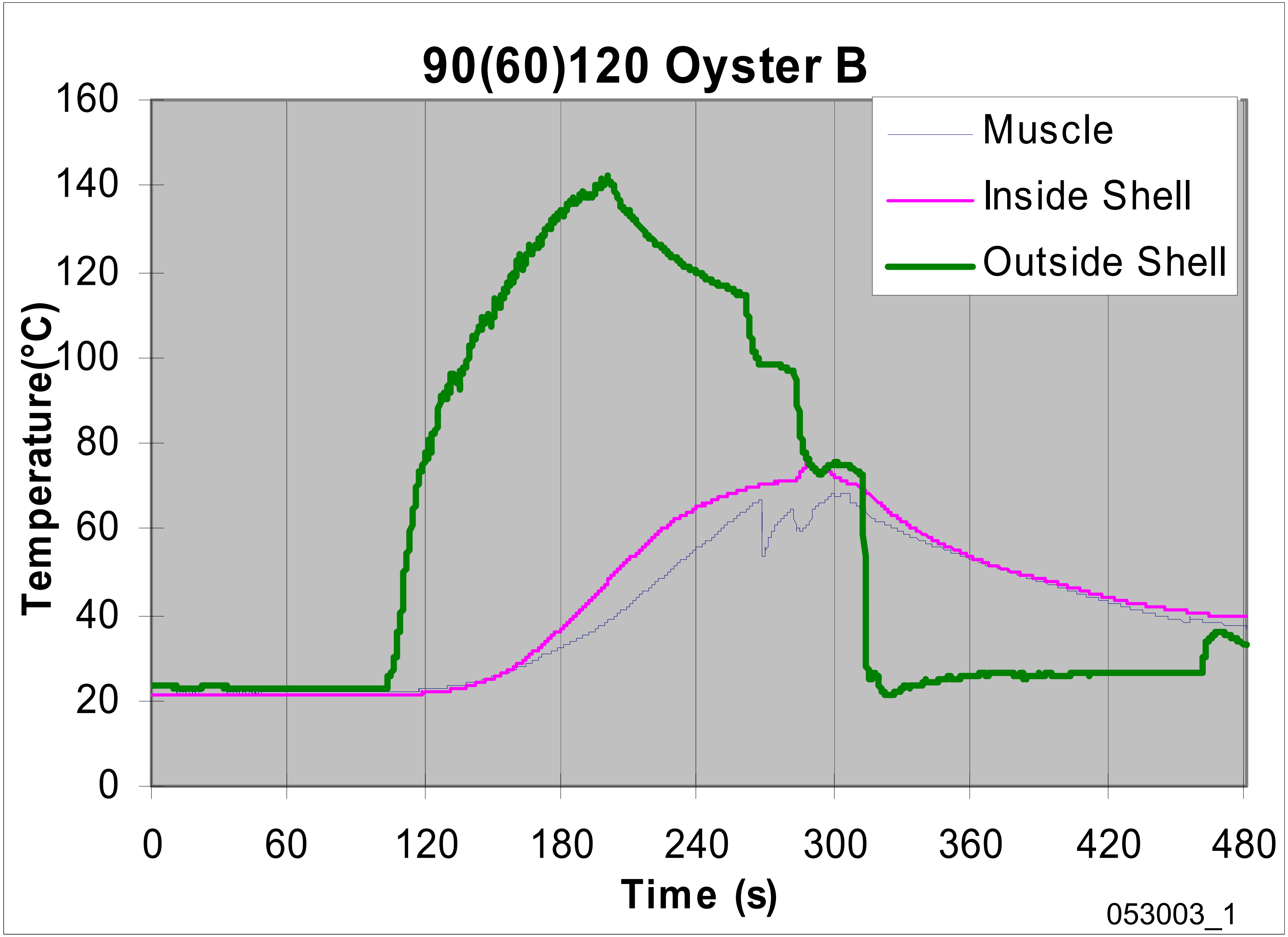
From these results, indications are that a particular microorganism might be confounding the results by surviving the mild heat treatment and then growing with less competition in a refrigerated environment. Additional testing will be conducted to determine if *Pseudomonas spp*., which is thermo-tolerant and psychrotrophic, might be responsible for some of the trends observed.

This low-pressure, steam-based, oyster shucking process would offer smaller shellfish processors an alternative to current oyster shucking technologies that require large capital investment. Steam and ice are readily available at most processing facilities and the lower pressures required by this process pose less of a safety hazard to workers. This technology would allow smaller processors an opportunity to reduce their skilled labor force by producing oysters that are either partially or fully shucked. Since the steam treatment causes relaxation and release of the oyster meat, yield also would potentially be increased as the shuckers would have increased access to the meat.

Appendix A. Processing Graphs

This appendix contains the processing graphs for each of the thermal oyster shucking treatments. The treatments are indicated on the graphs by three to four numbers in sequence. Where four numbers are listed, such as 30-45-60-240, the first number would indicated a 30 second pre-heat, the second a 45 second steam injection, the third a 60 second hold and finally the fourth, a 240 second post-process chill. Where only three numbers are listed, no pre-heat was included in the treatment and the three numbers would represent the time of steam injection, hold and post-process chill in seconds. The bottom of the graphs have the treatment recorded which is comprised of a date stamp and run number for the day.


90(60)120 Oyster A
160
140
120
100
80
60
40
20
0
Temperature (°C)
0
60
120
180
240
300
360
420
480
Time (s)
Muscle
Inside Shell
Outside Shell
053003_1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Muscle
Inside Shell
Outside Shell
Temperature(°C)
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420
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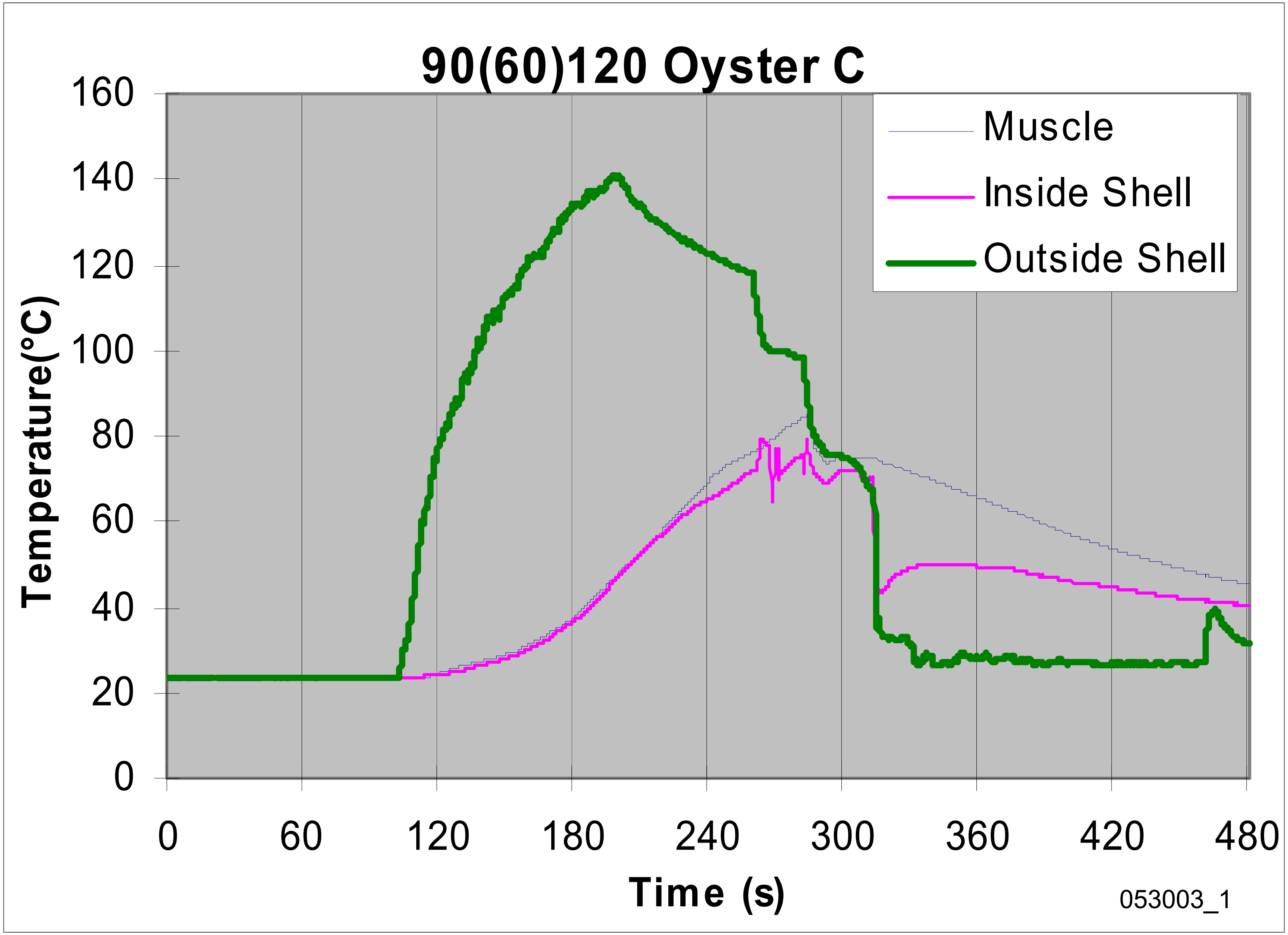
Time (s)
053003_1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Temperature(°C)
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Time (s)
Muscle
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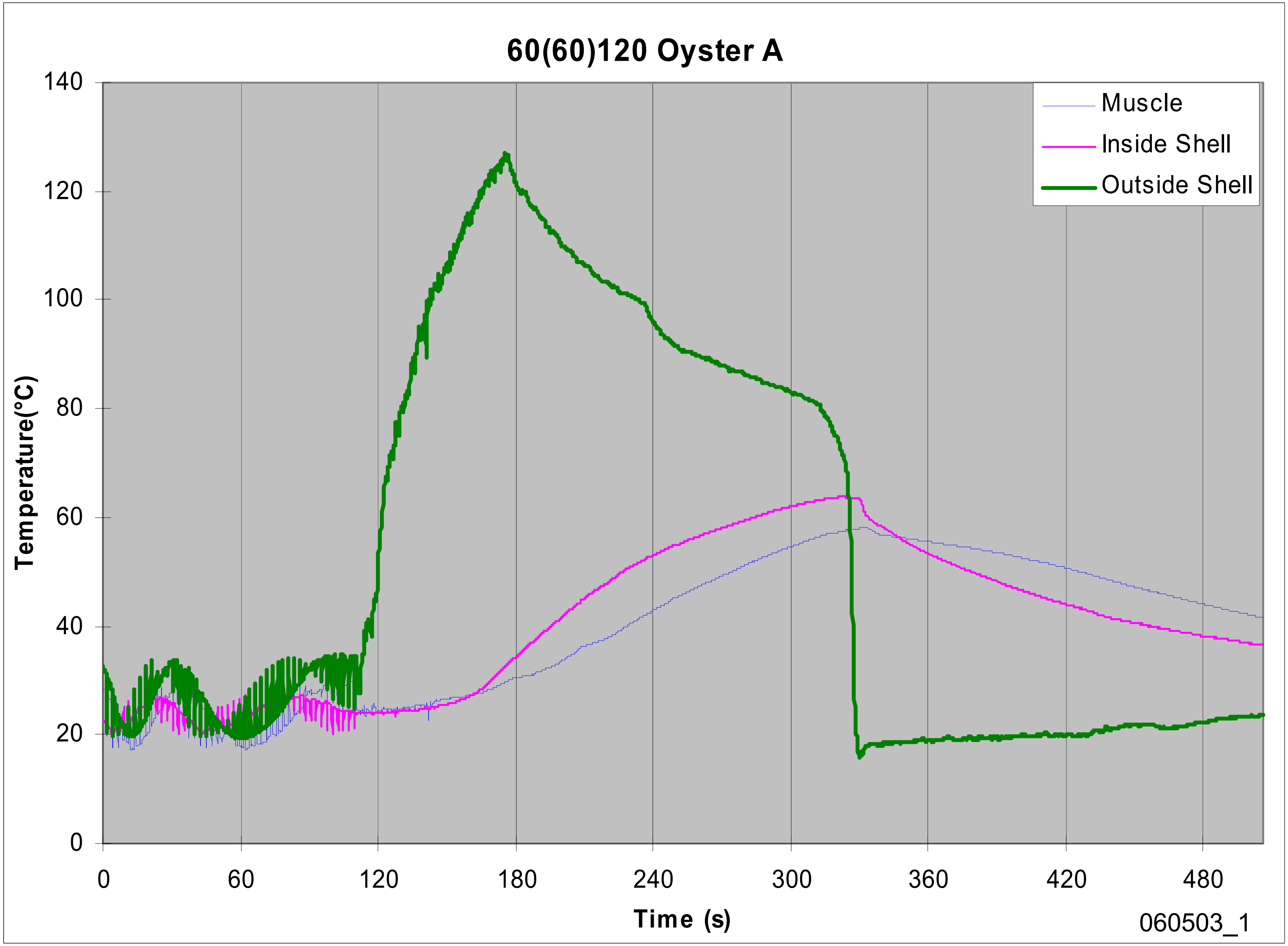
053003_1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Temperature(°C)
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Time (s)
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Muscle
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Outside Shell
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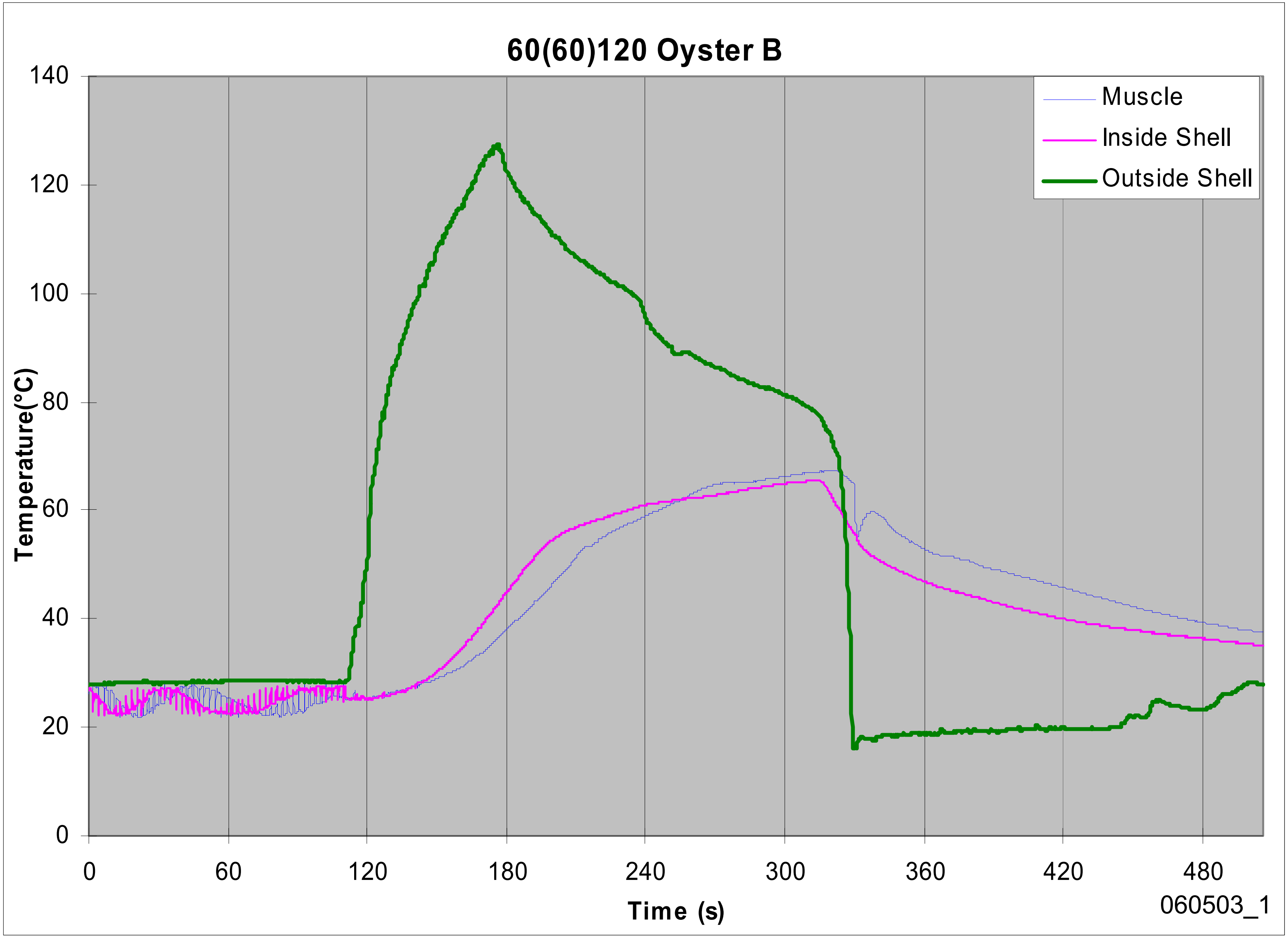
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Temperature(°C)
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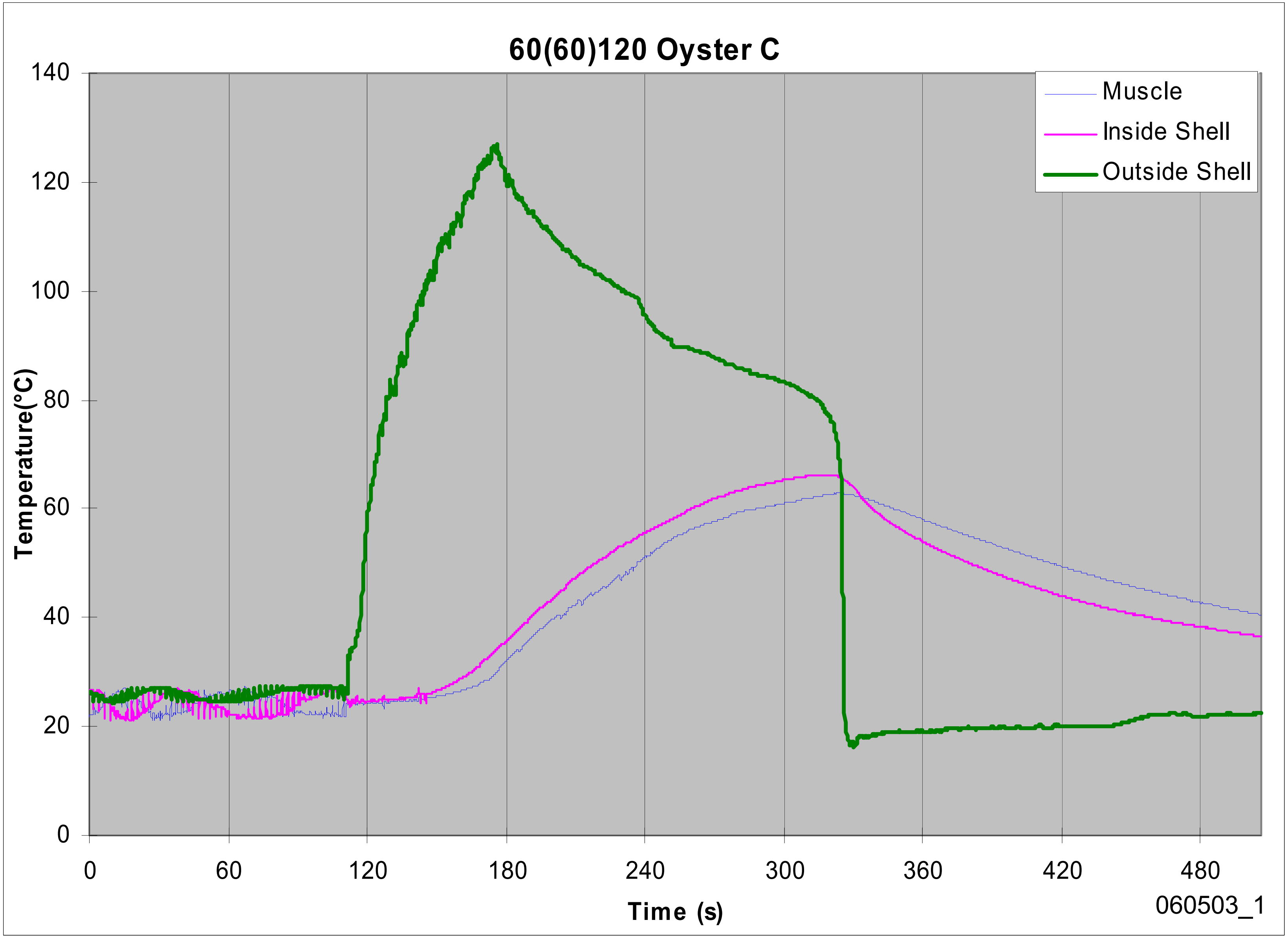
Time (s)
060503_1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Temperature(°C)
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Time (s)
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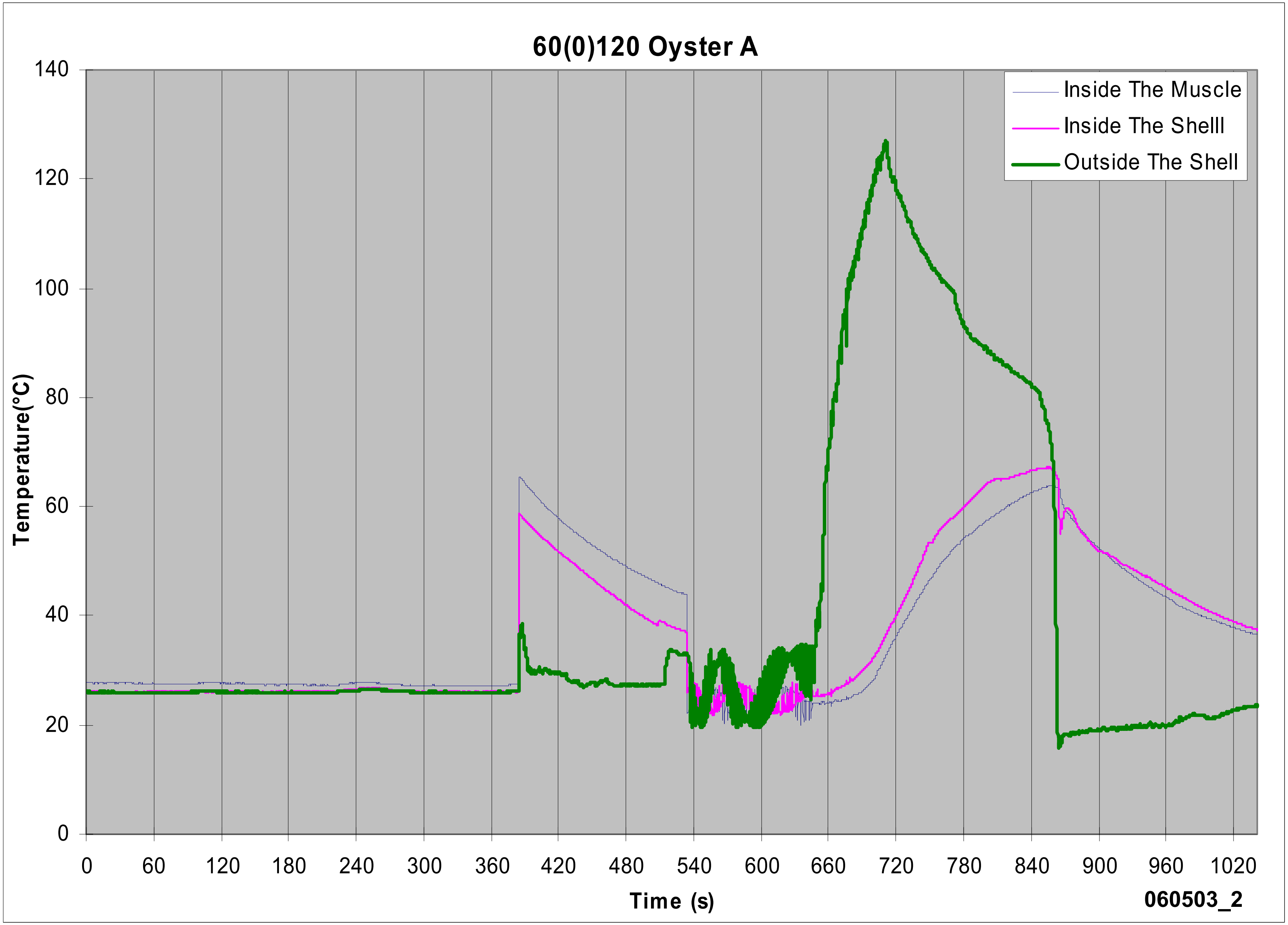
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Temperature(°C)
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Time (s)
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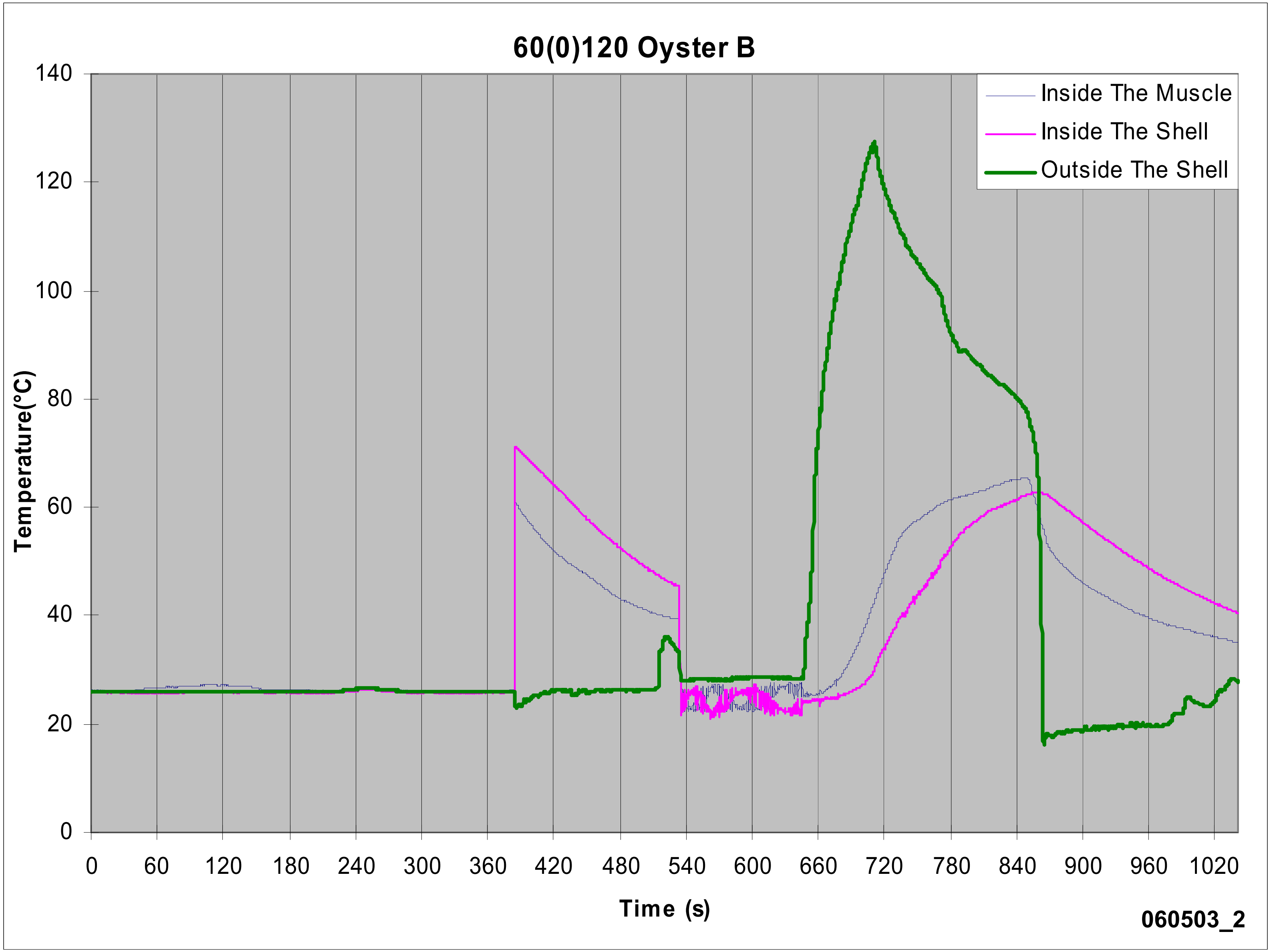
Inside The Shelll
Outside The Shell
060503_2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Inside The Shell
Outside The Shell
Temperature(°C)
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Time (s)
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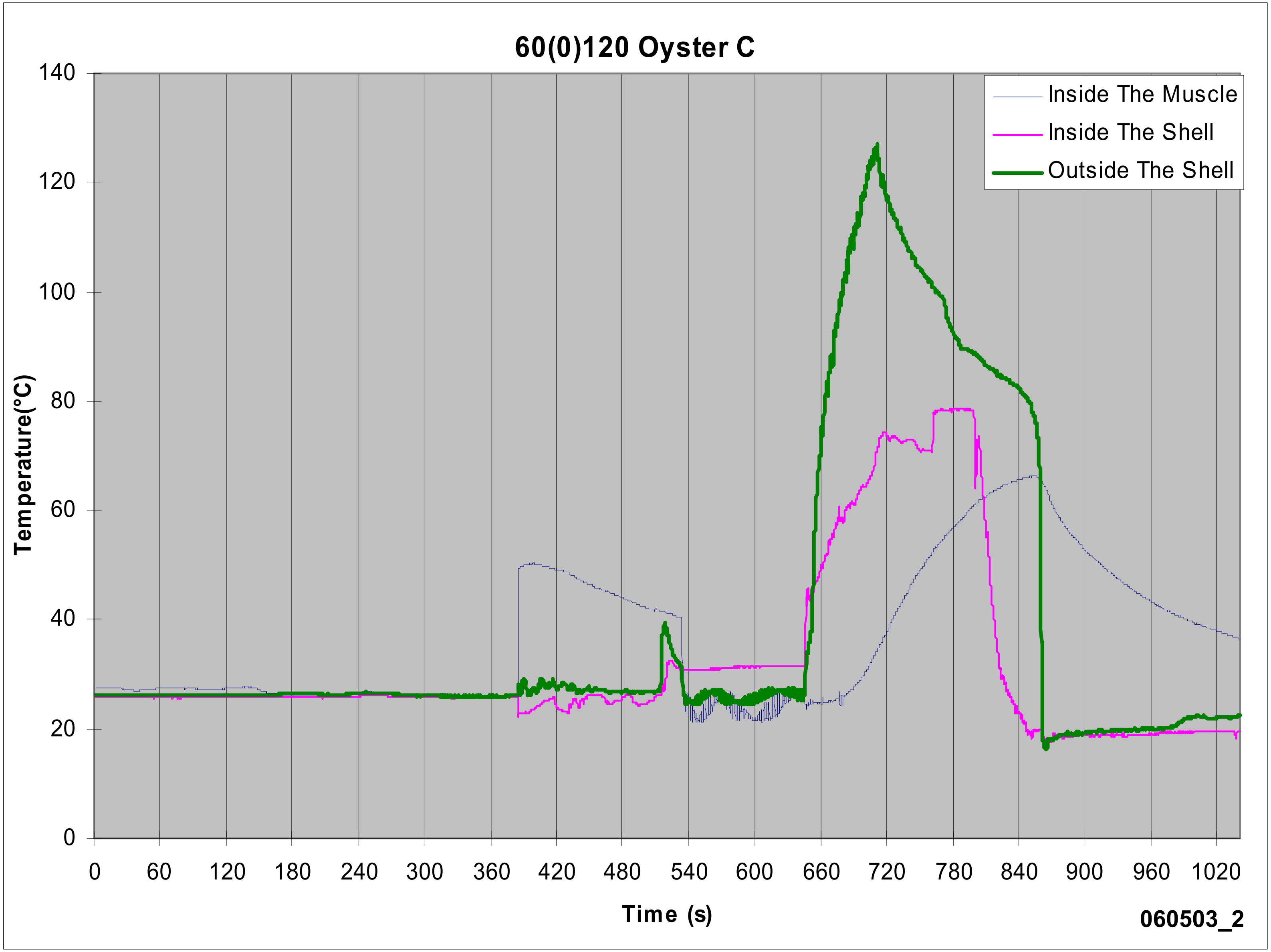
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Time (s)
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Inside The Shell
Outside The Shell
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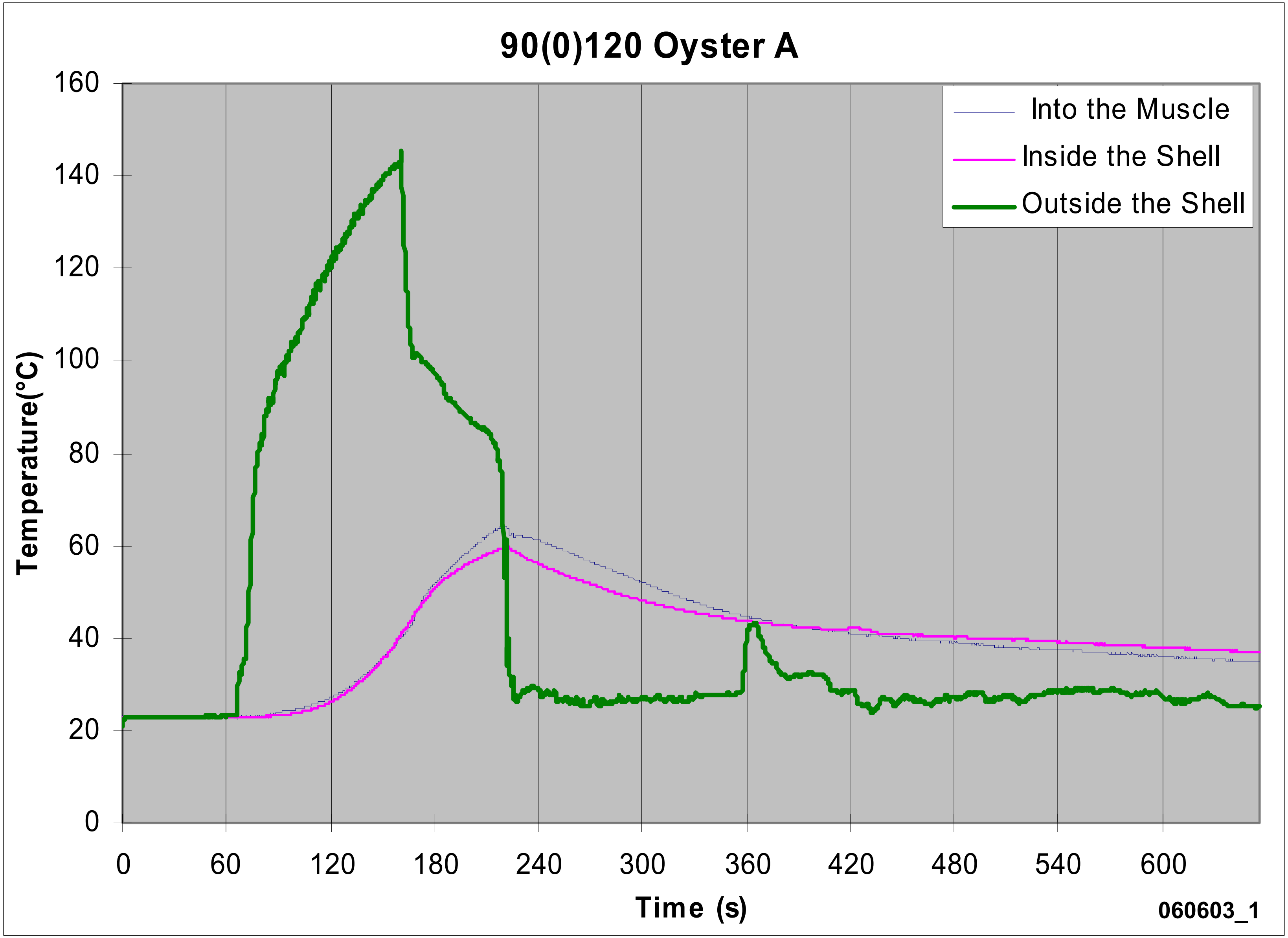
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Temperature(°C)
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Time (s)
Into the Muscle
Inside the Shell
Outside the Shell
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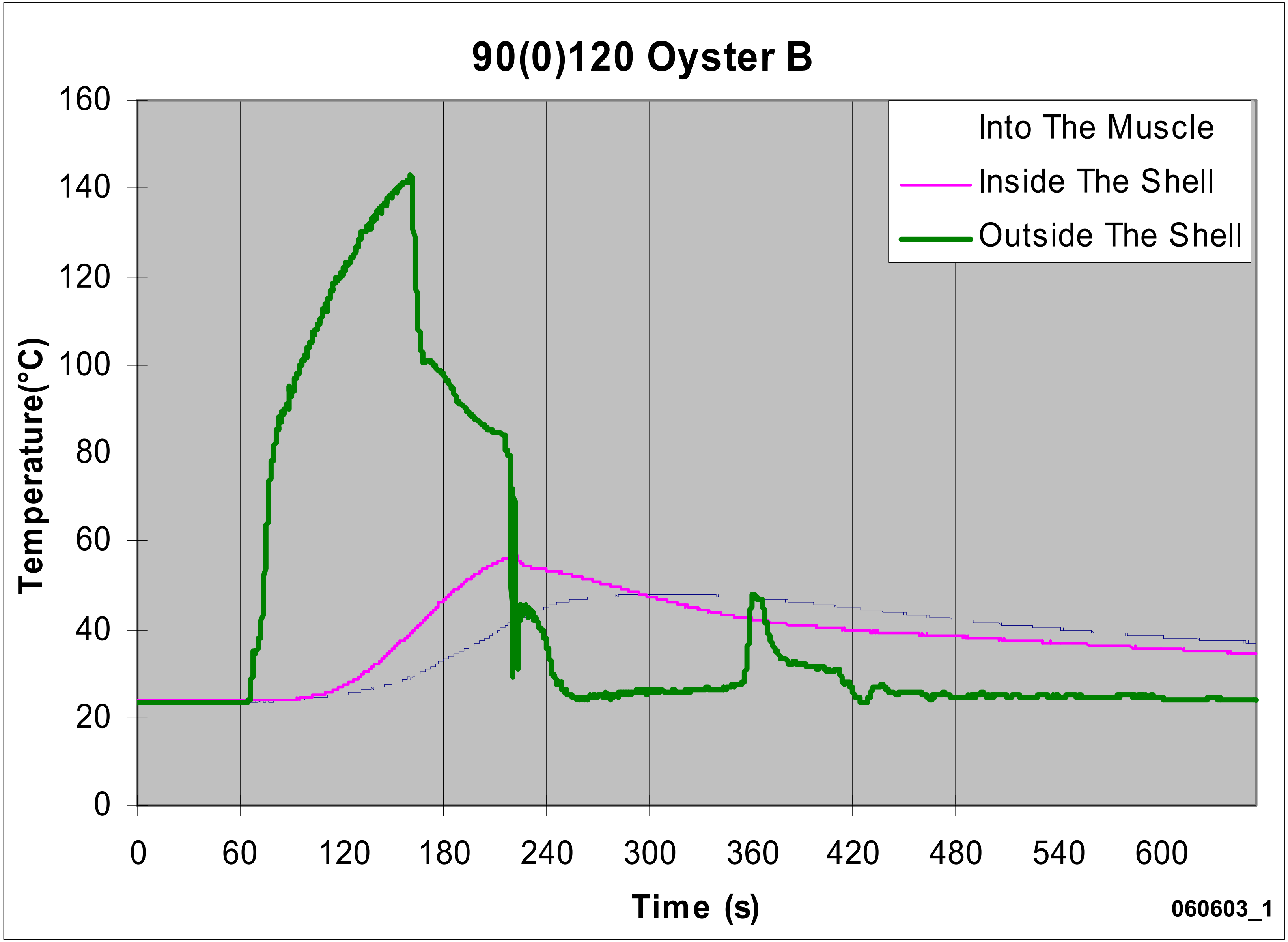
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Inside The Shell
Outside The Shell
Temperature(°C)
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Time (s)
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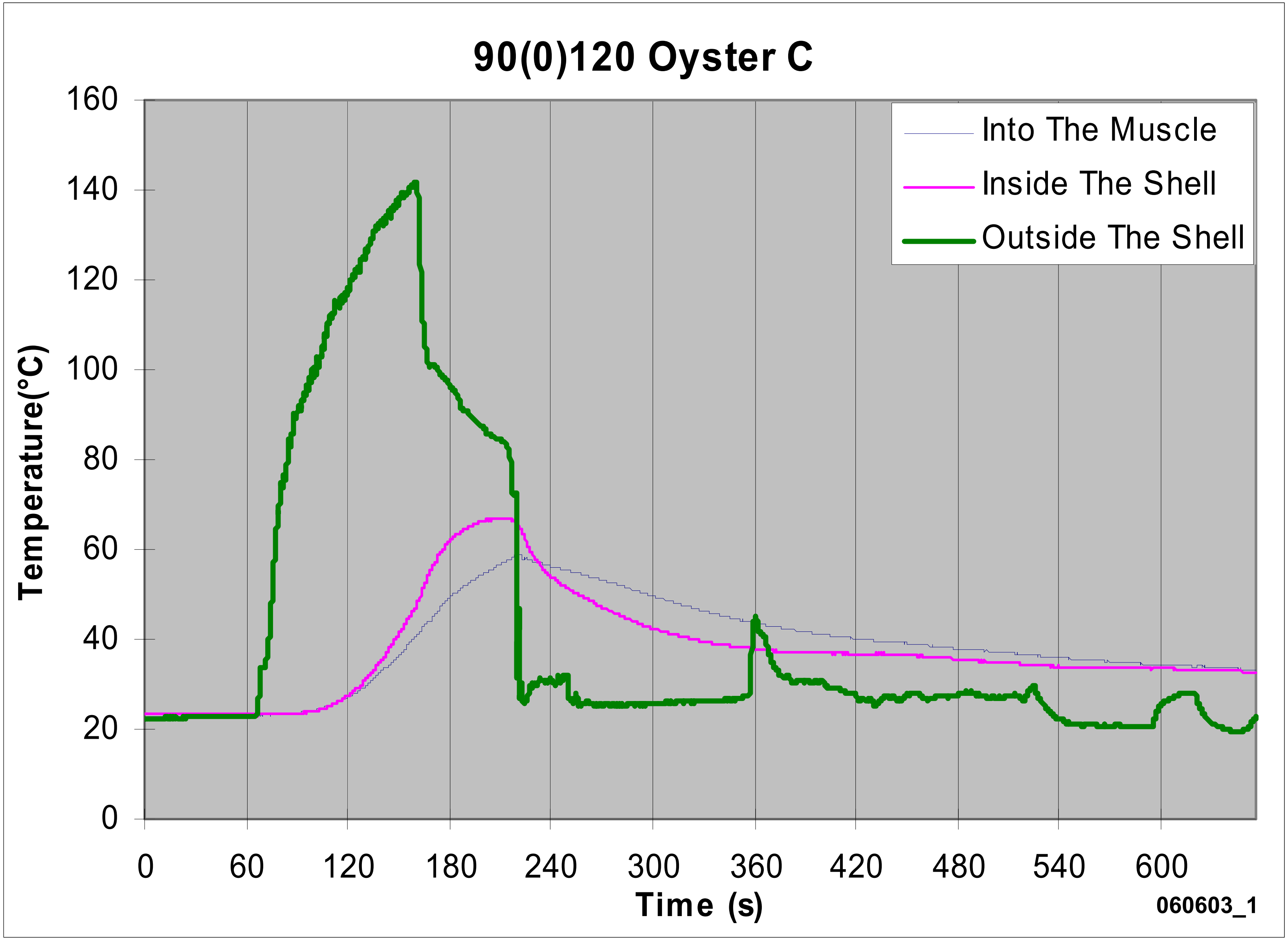
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Temperature(°C)
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Into The Muscle
Inside The Shell
Outside The Shell
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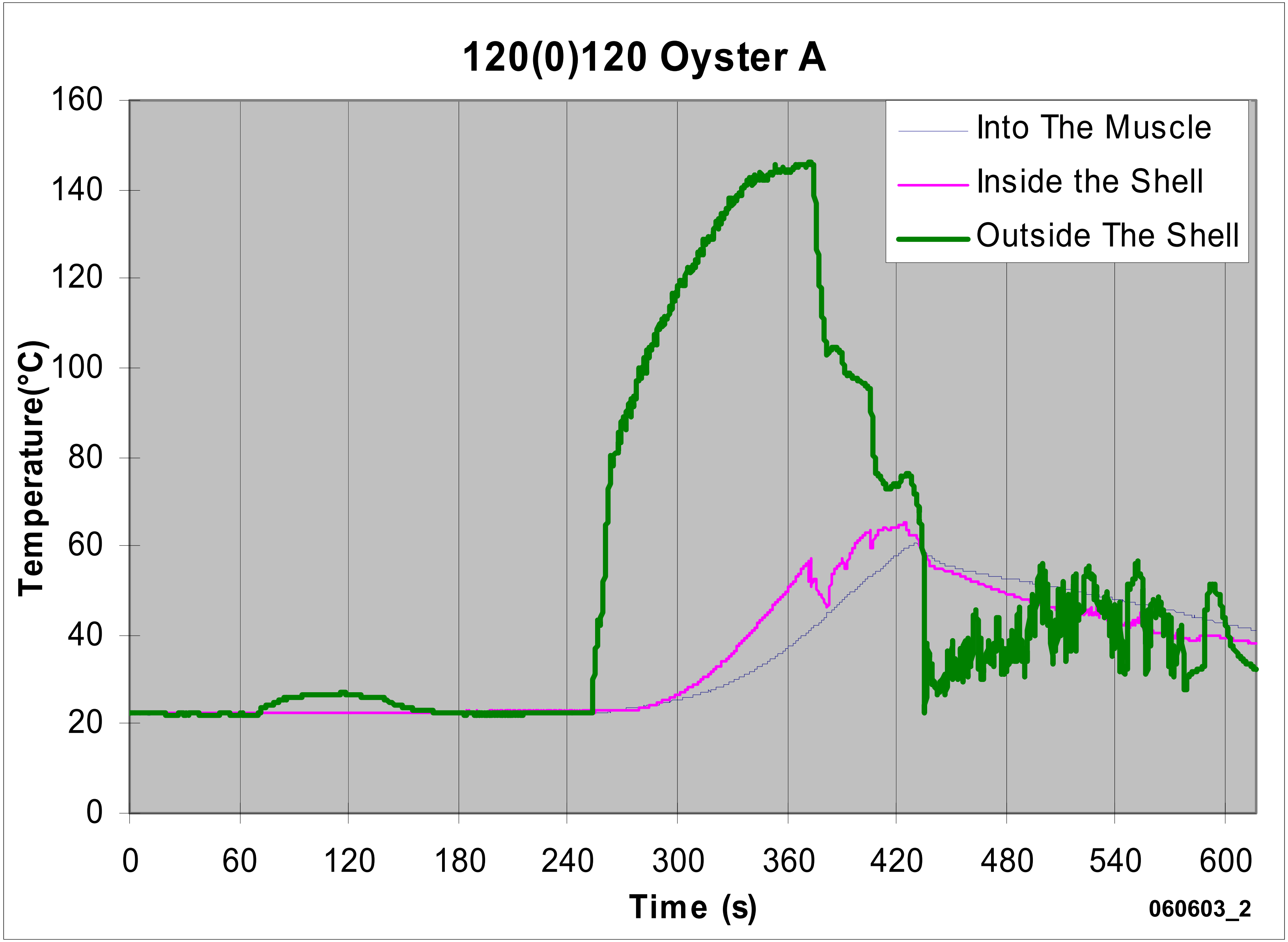
Time (s)
060603_1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Time (s)
Into The Muscle
Inside the Shell
Outside The Shell
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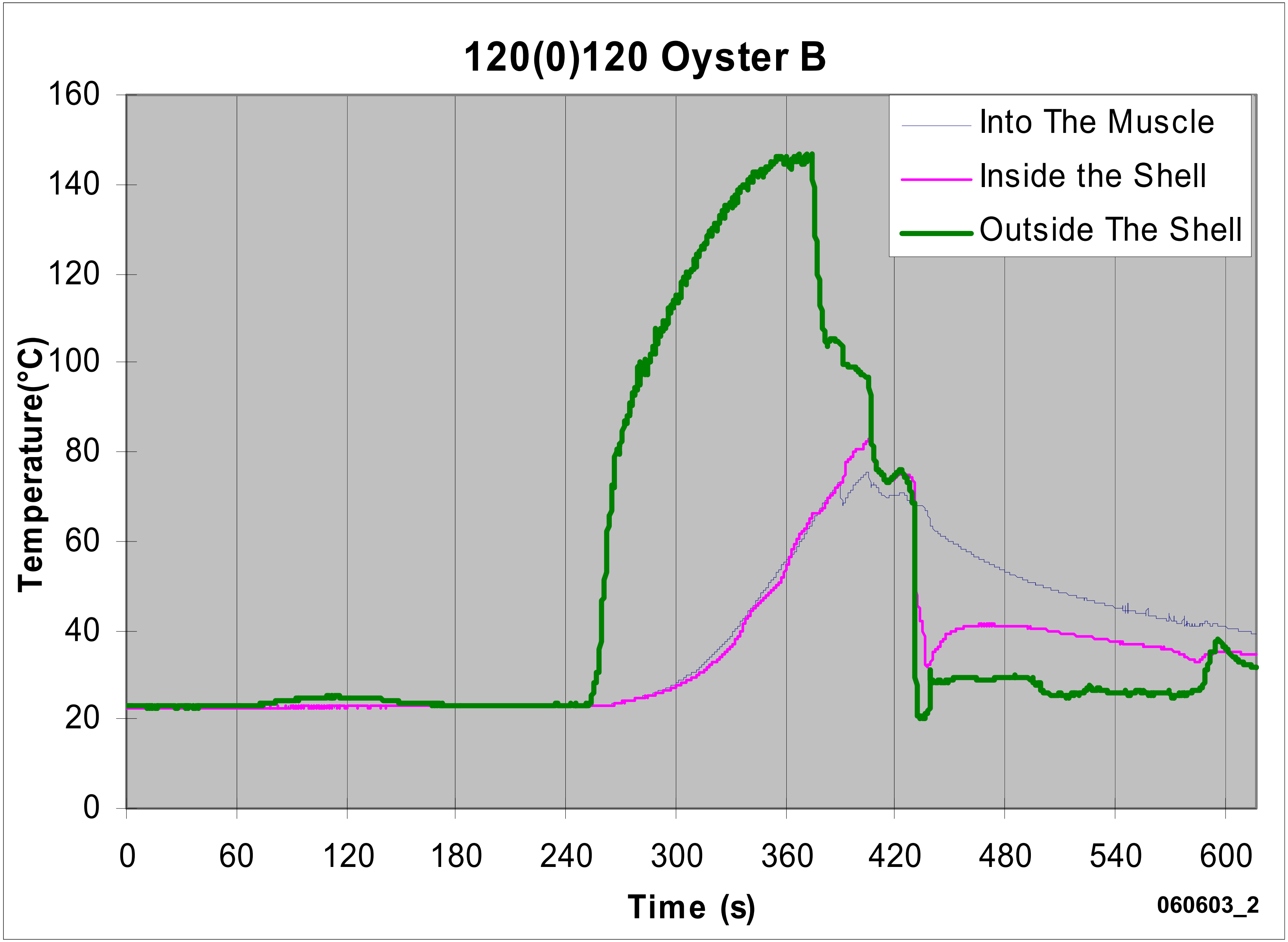
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Time (s)
Into The Muscle
Inside the Shell
Outside The Shell
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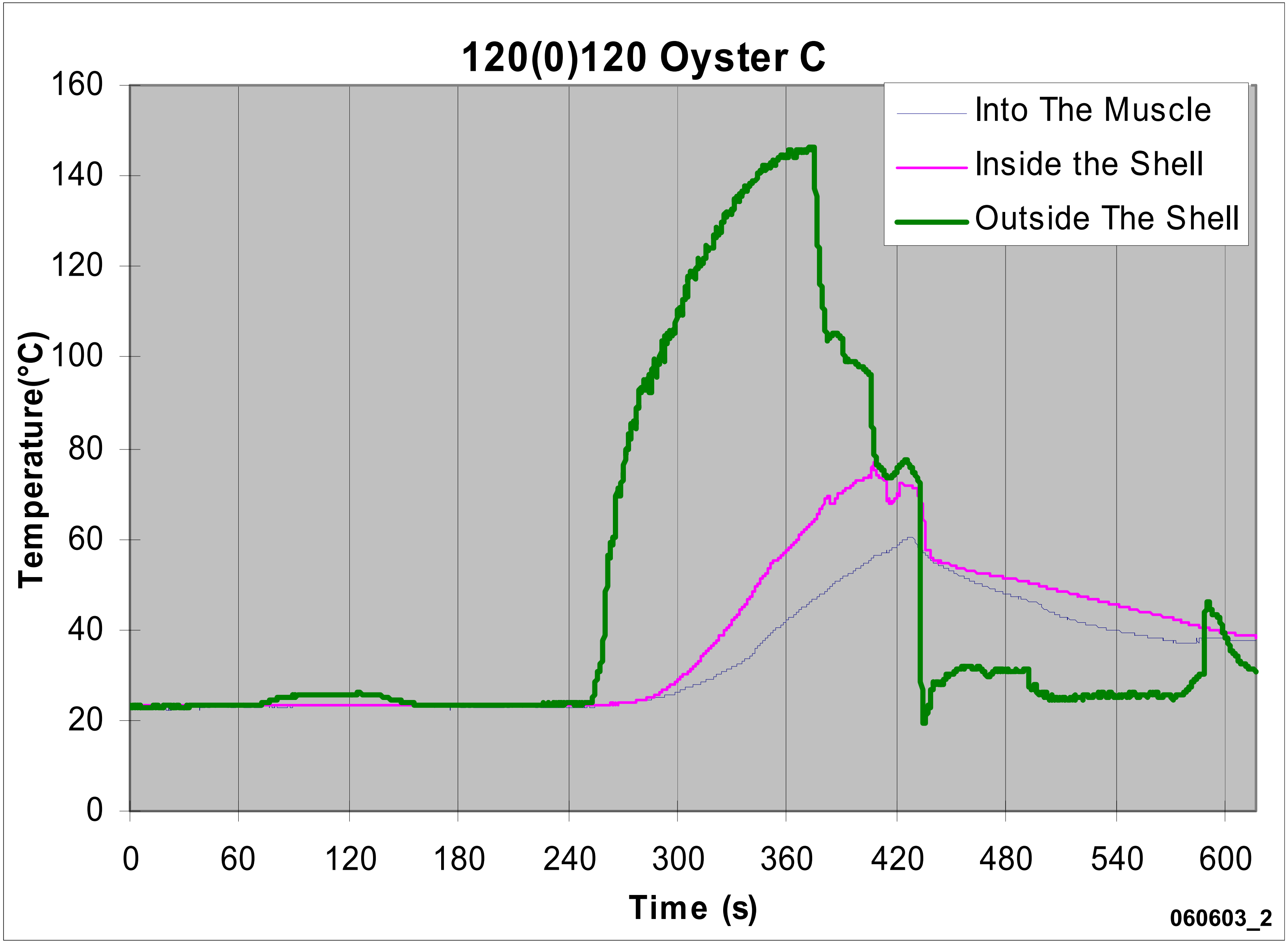
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Time (s)
Into The Muscle
Inside the Shell
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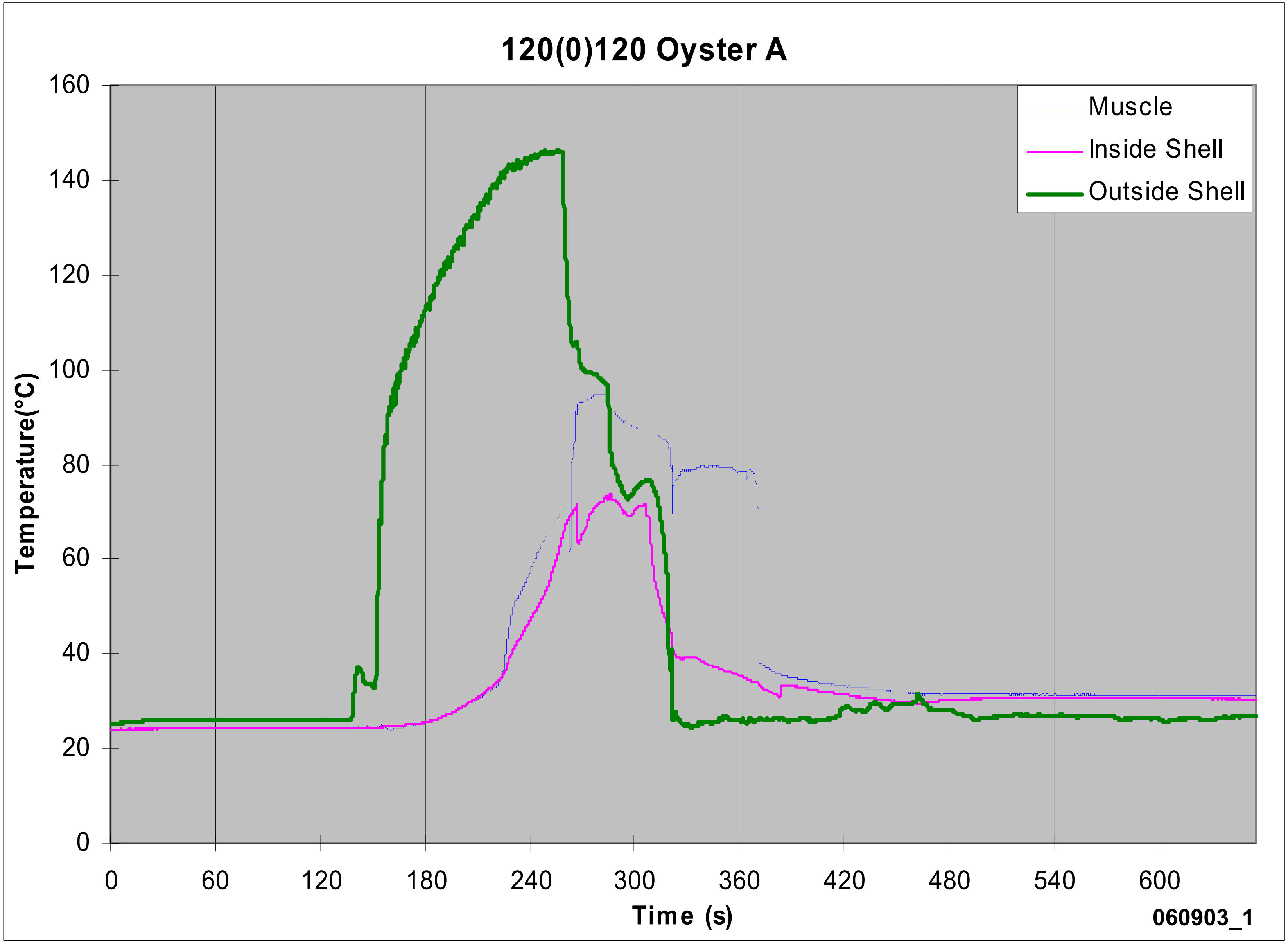
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Time (s)
Muscle
Inside Shell
Outside Shell
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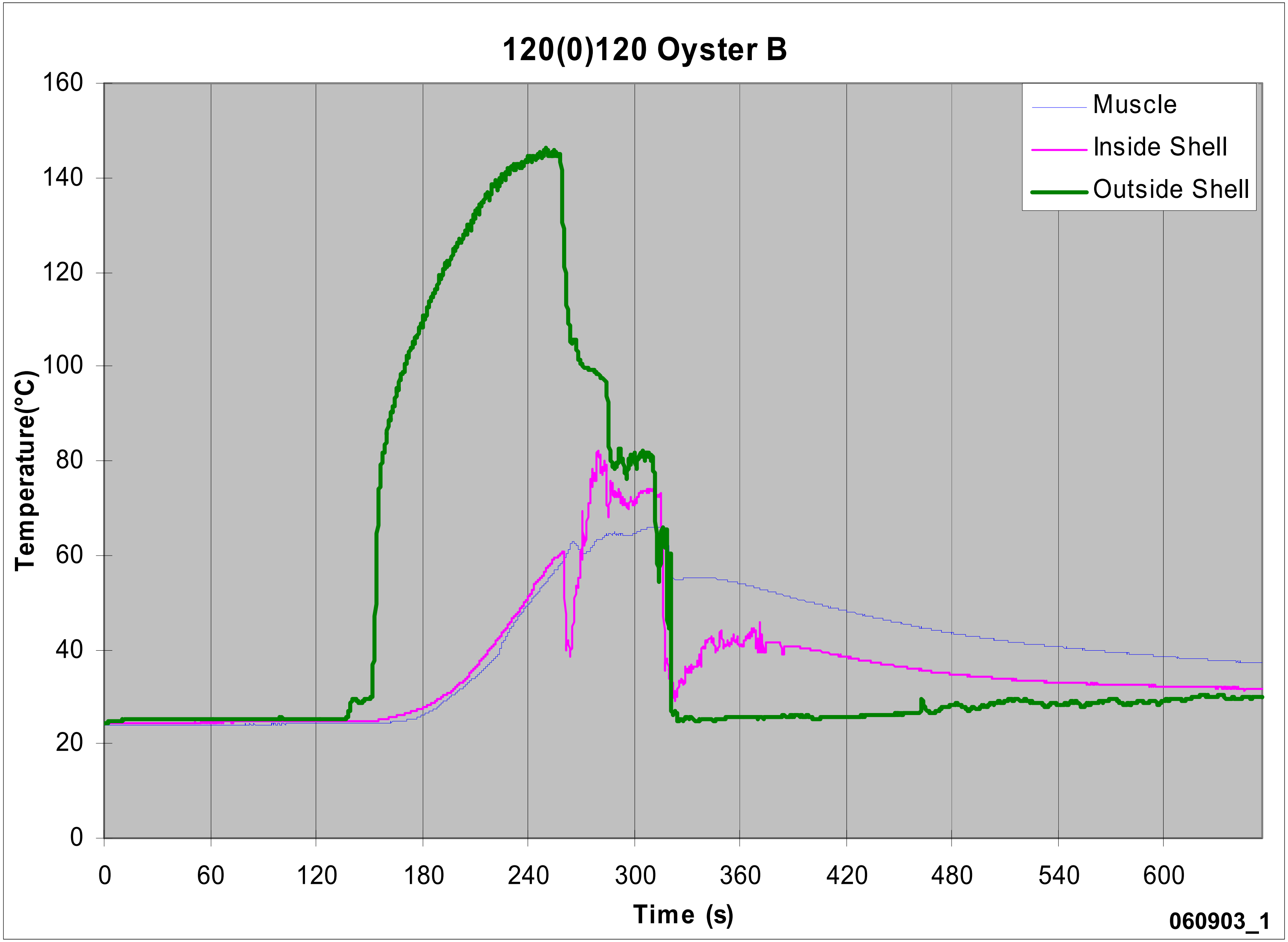
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Muscle
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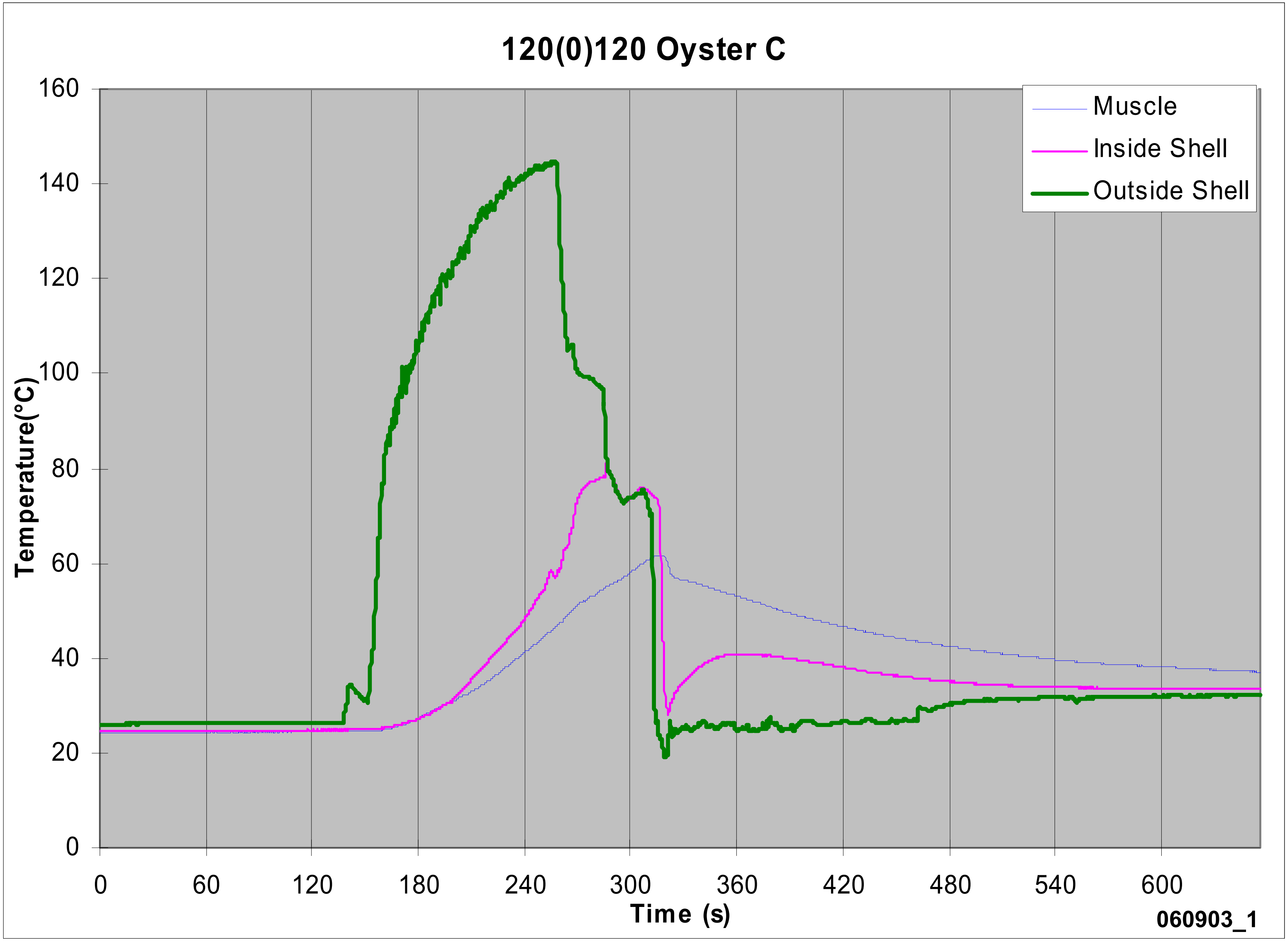
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Time (s)
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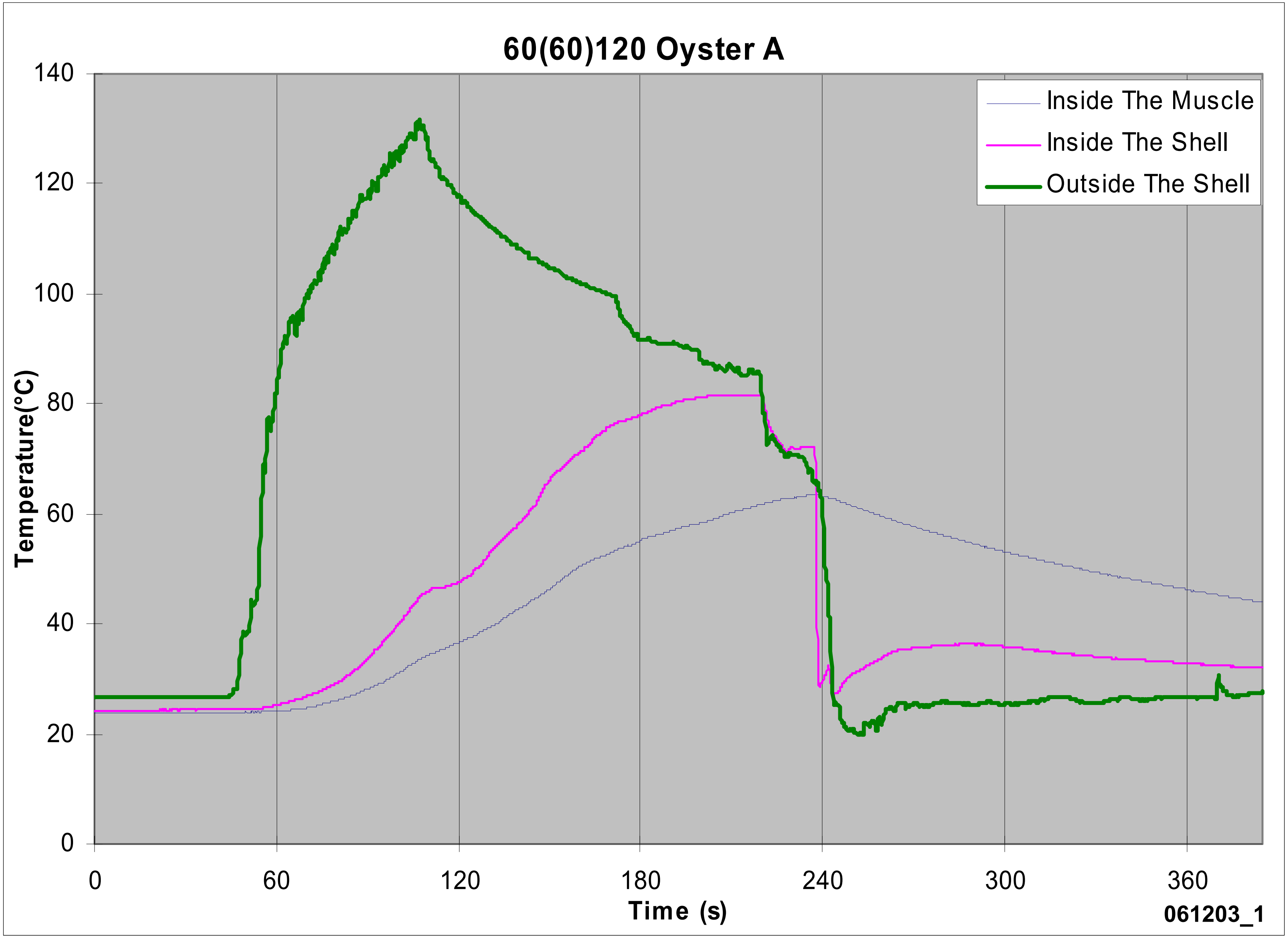
060903_1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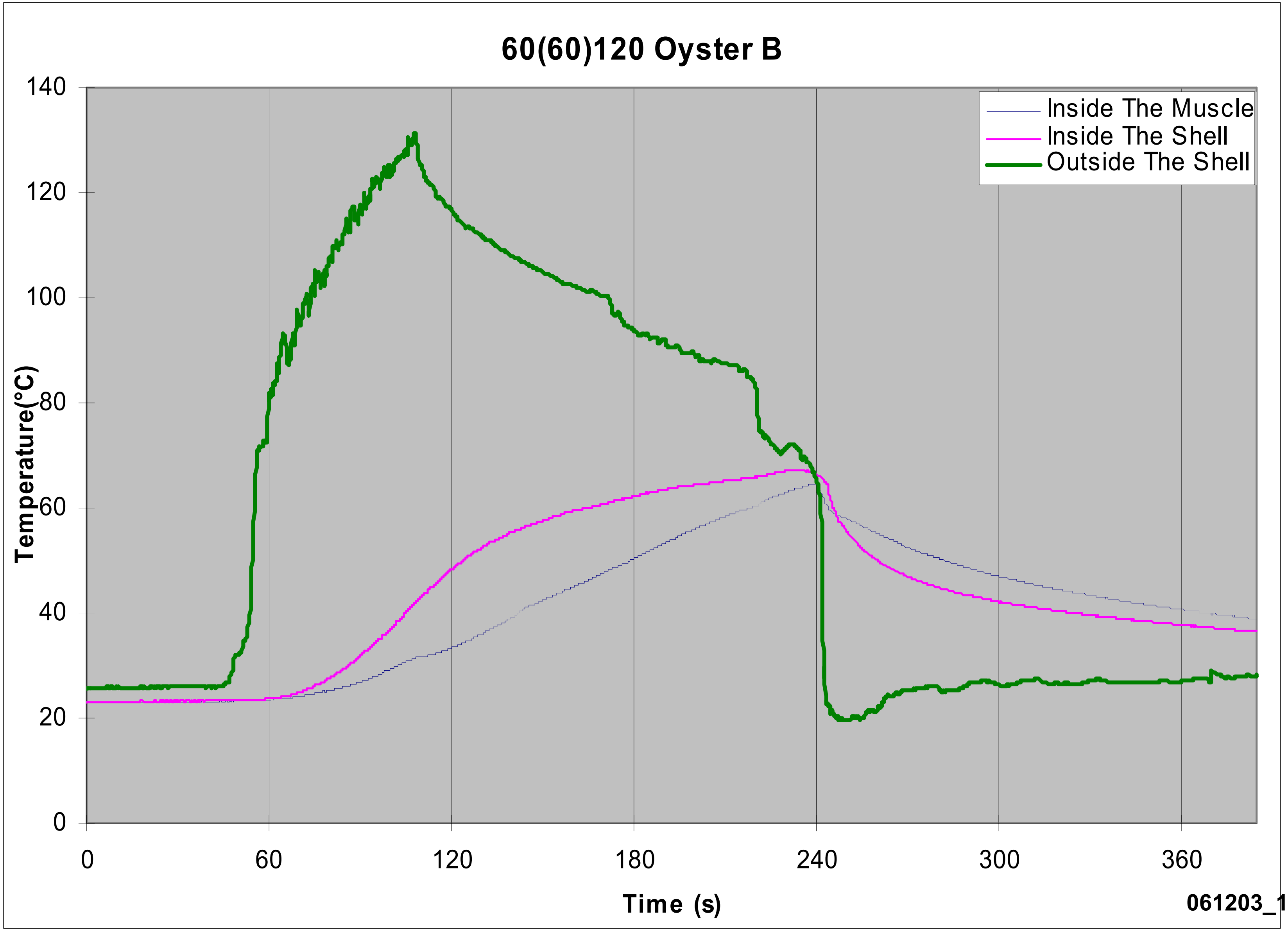
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Temperature(°C)
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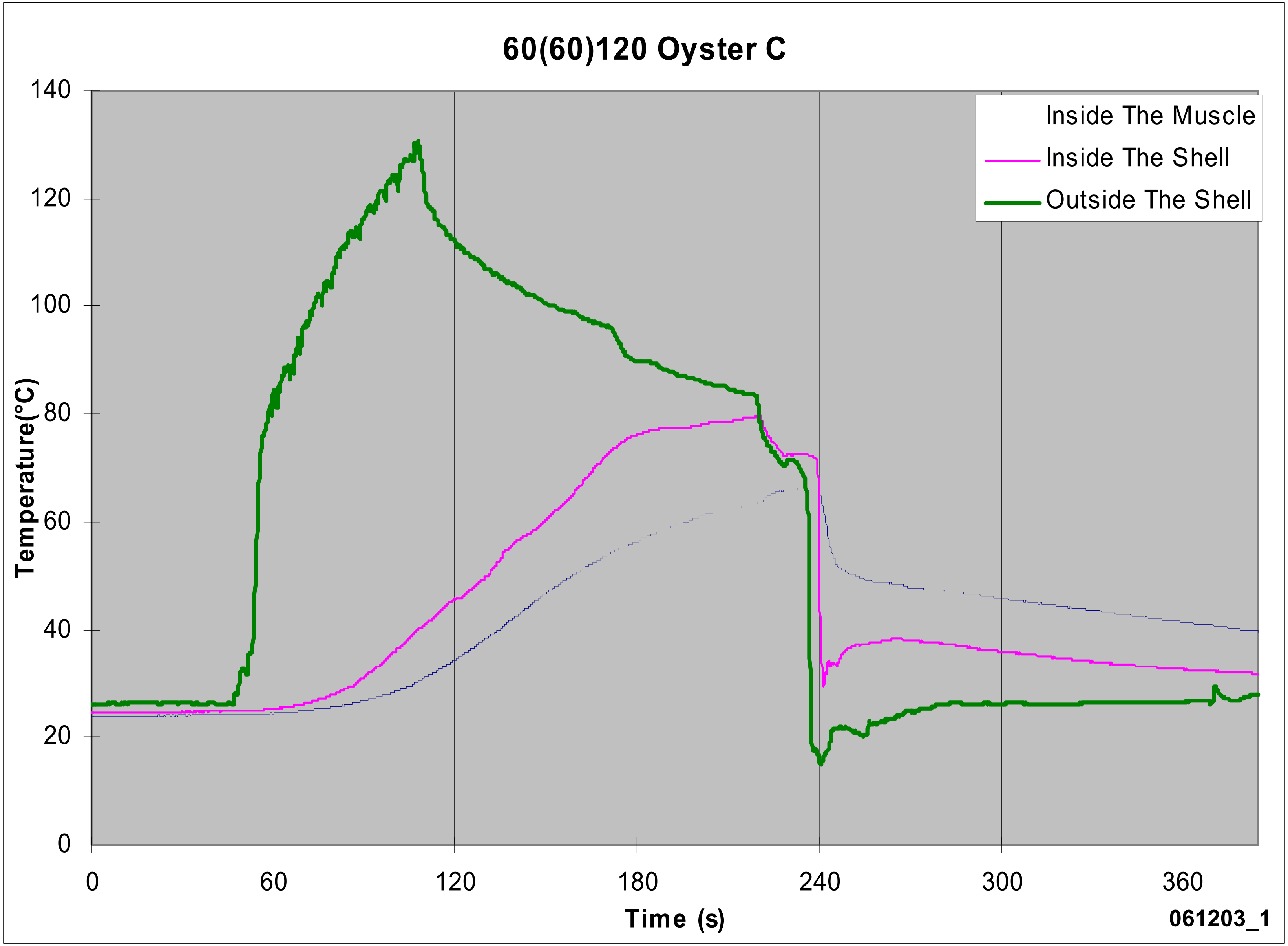
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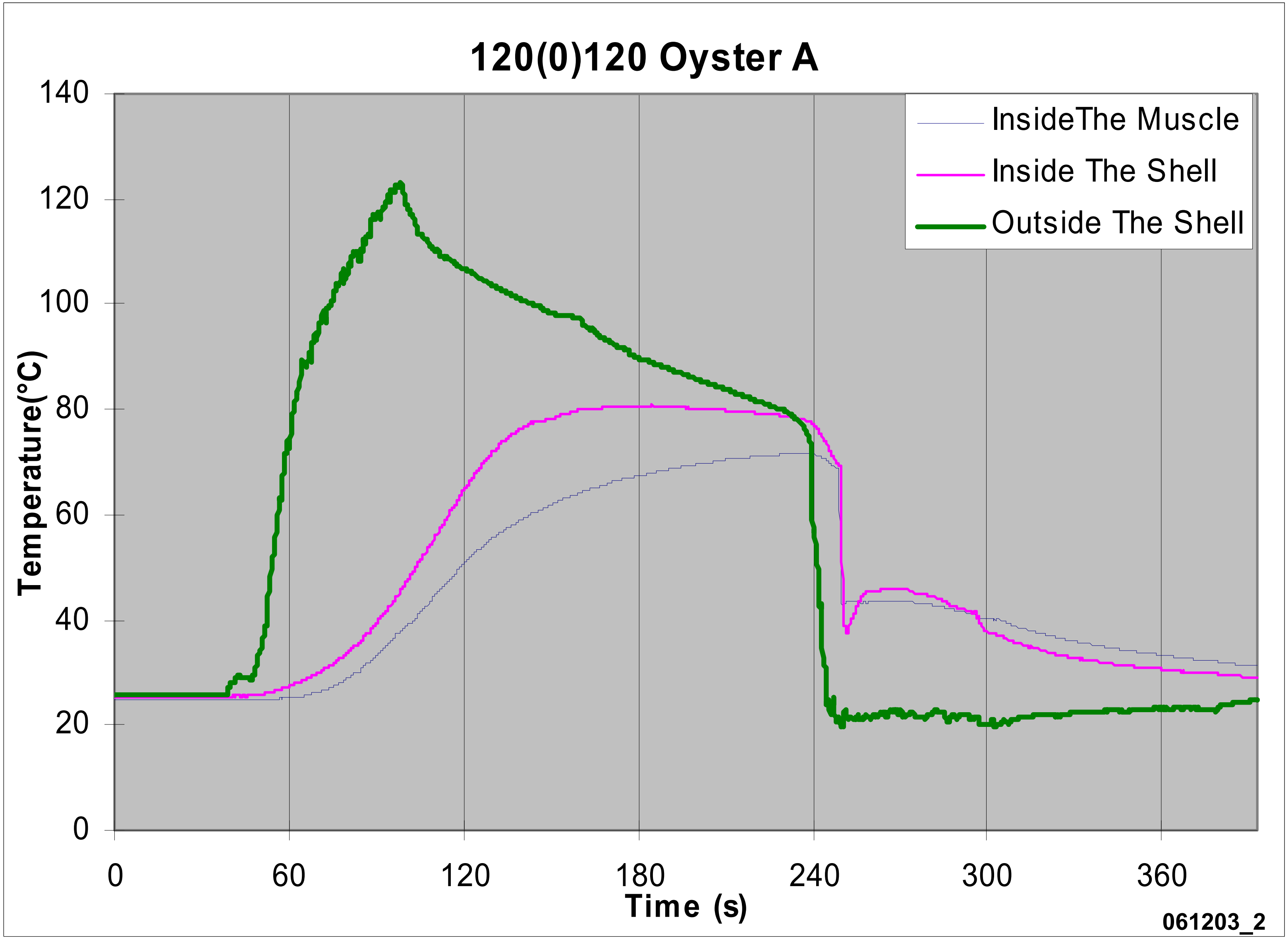
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Time (s)
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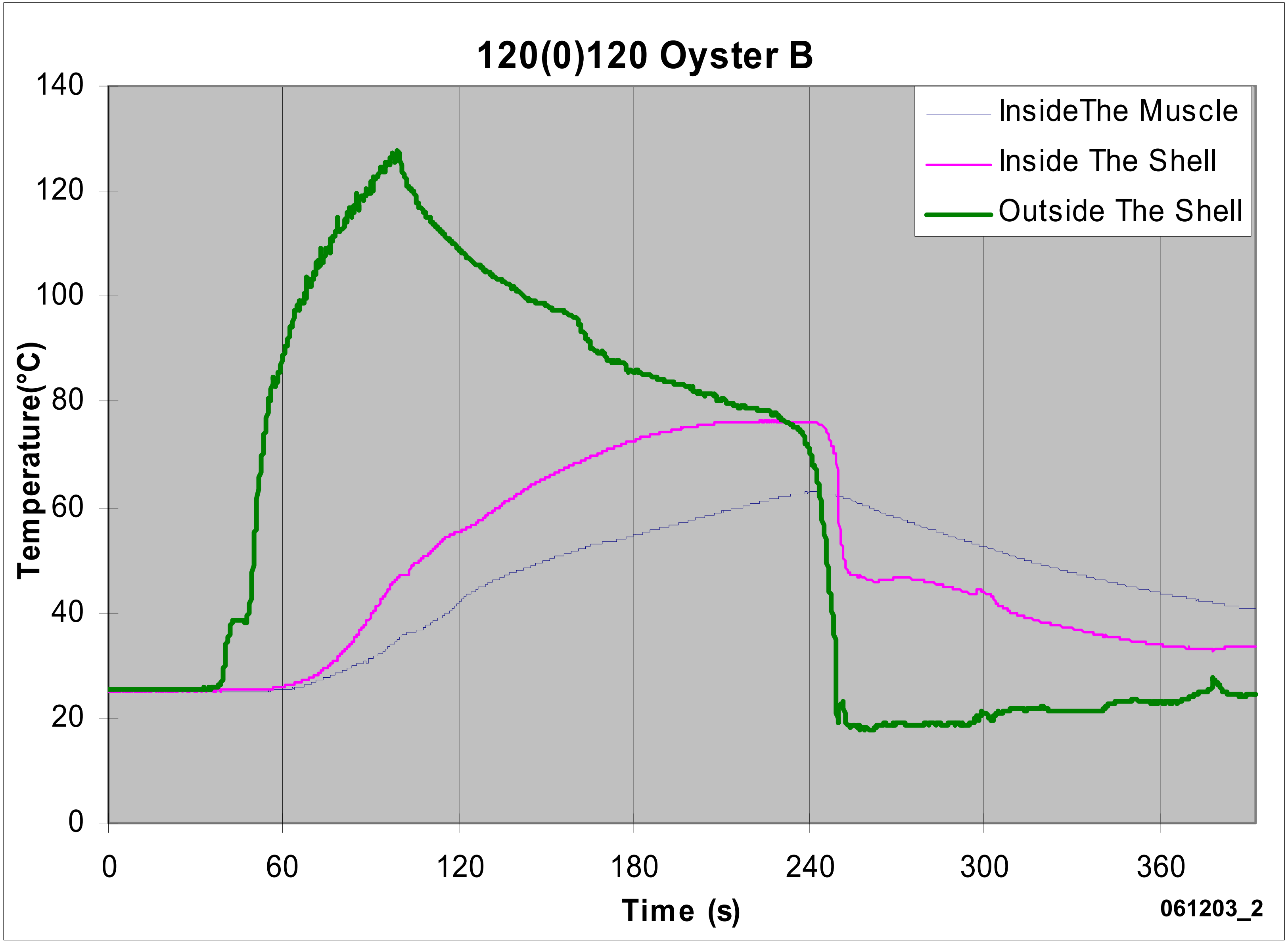
061203_2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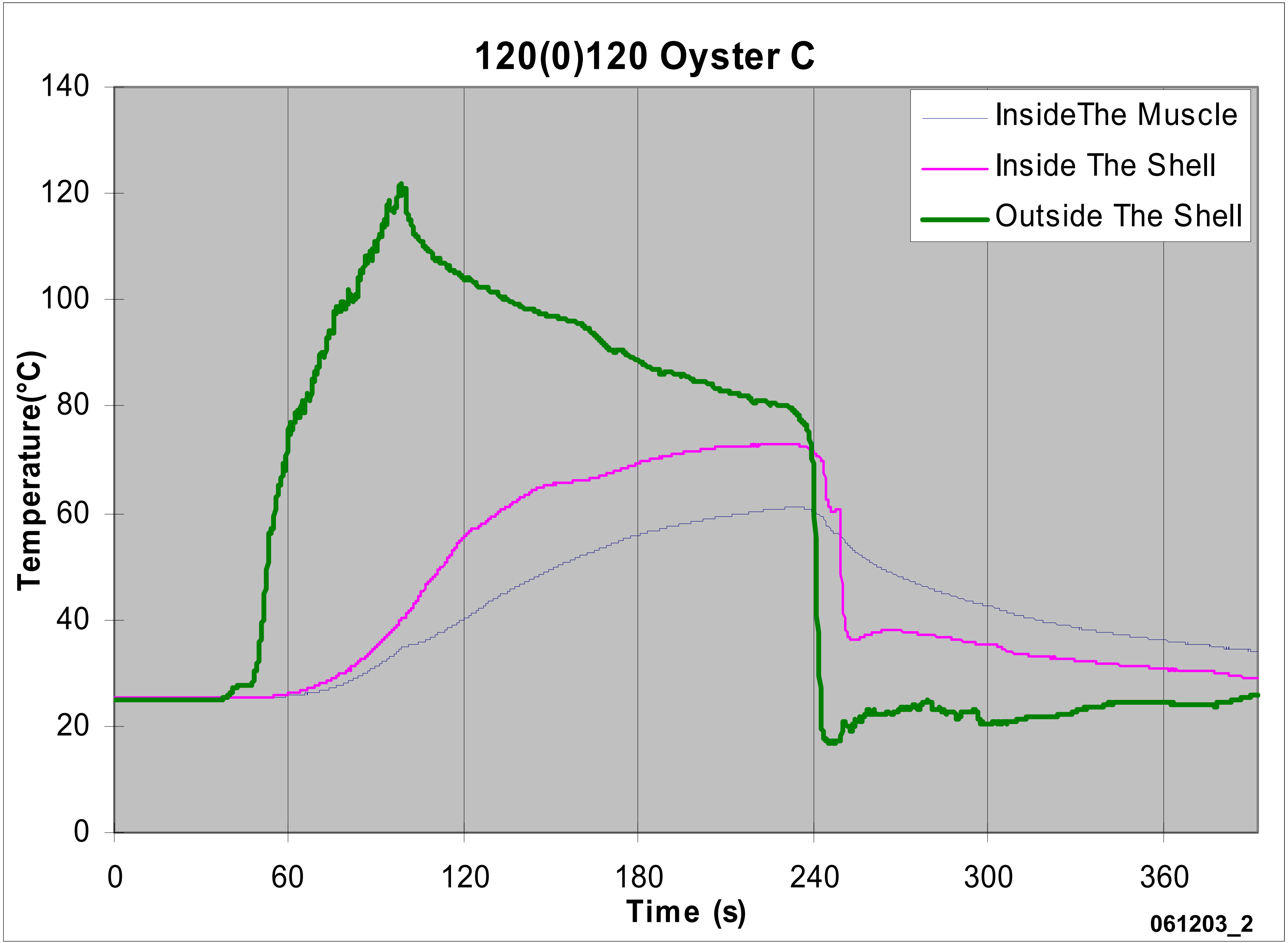
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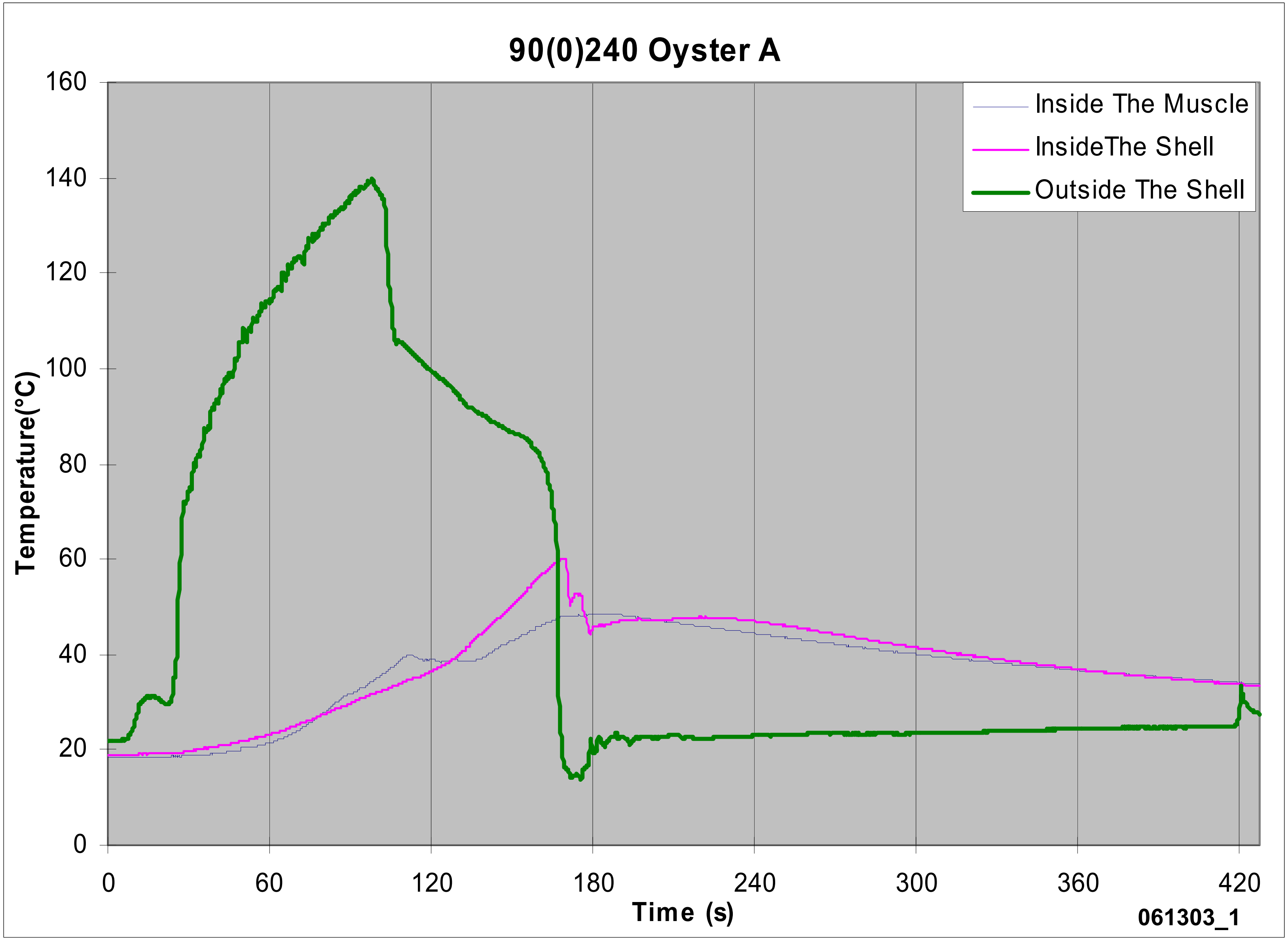
Time (s)
InsideThe Muscle
Inside The Shell
Outside The Shell
061203_2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Temperature(°C)
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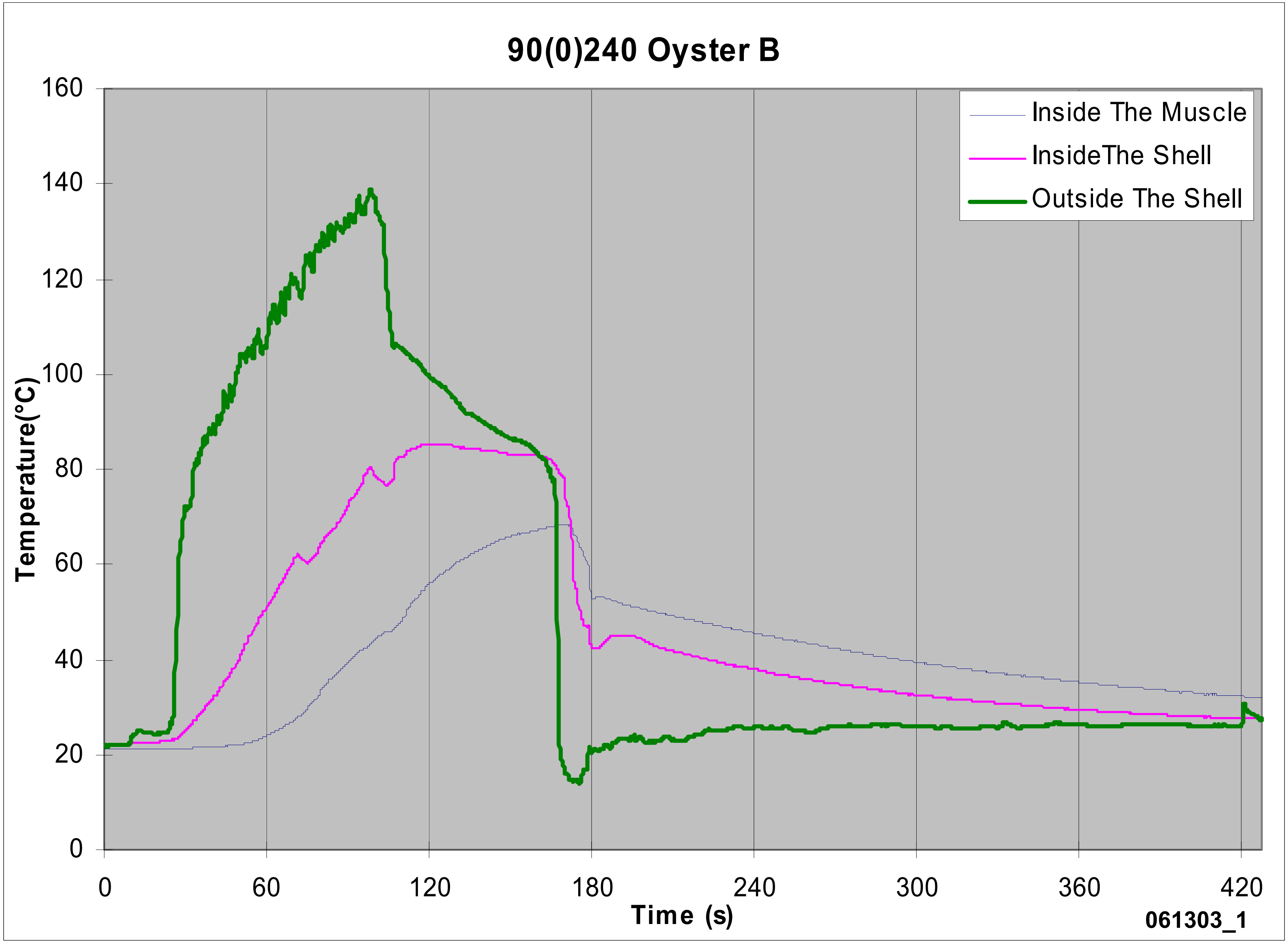
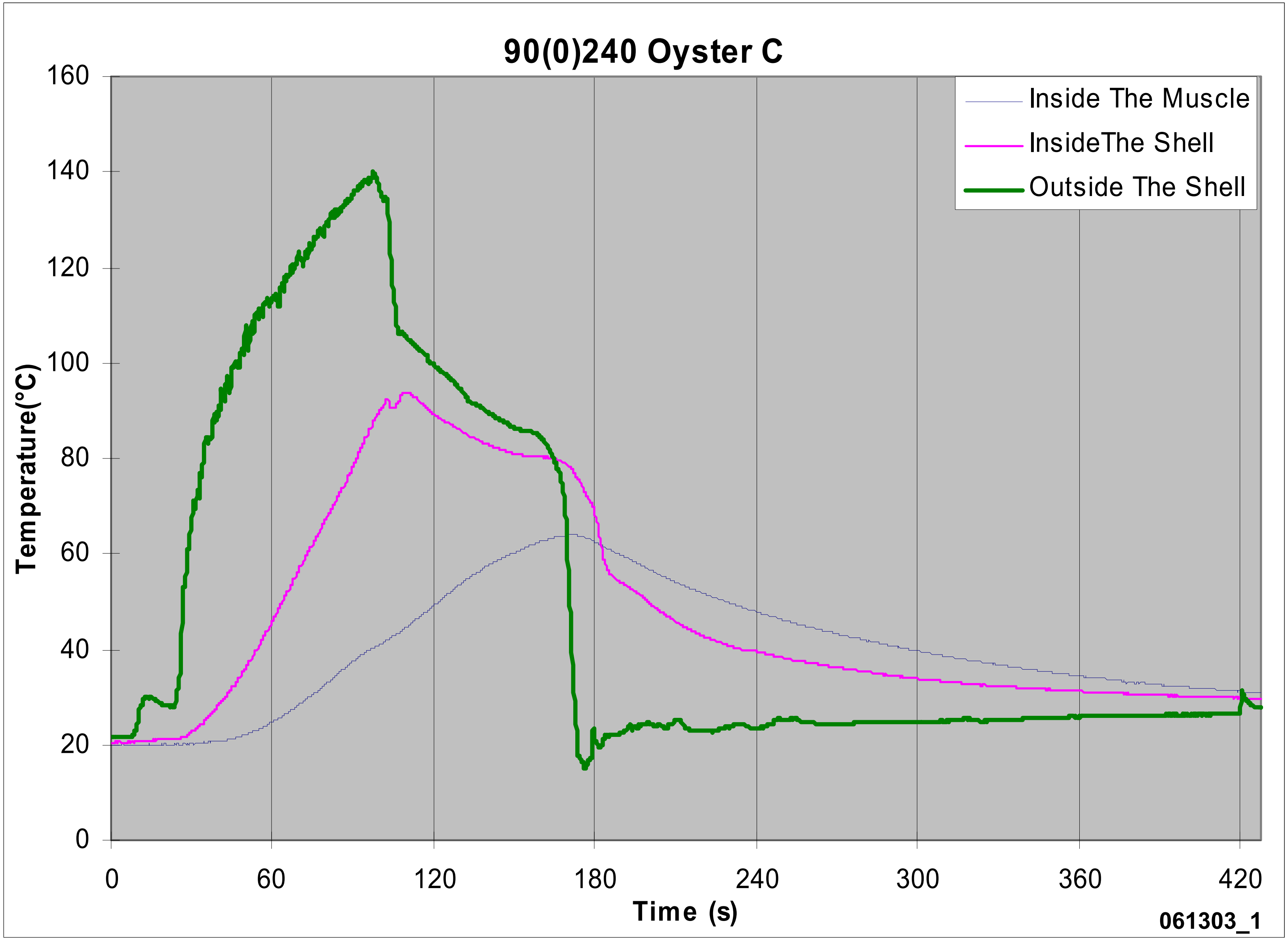
Time (s)
Inside The Muscle
InsideThe Shell
Outside The Shell
061303_1



90(0)240 Oyster B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Temperature(°C)
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Time (s)
Inside The Muscle
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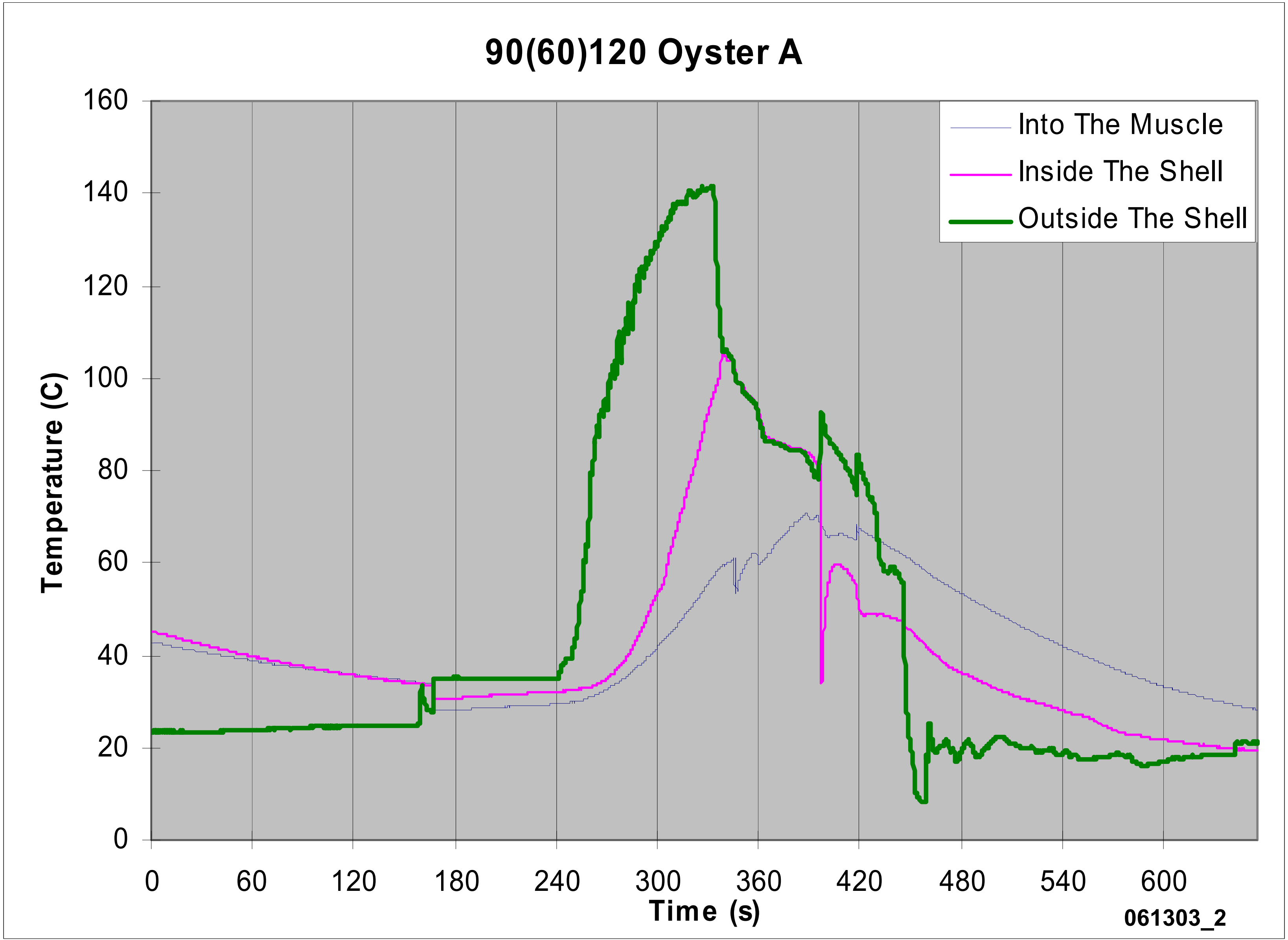
Outside The Shell
061303_1



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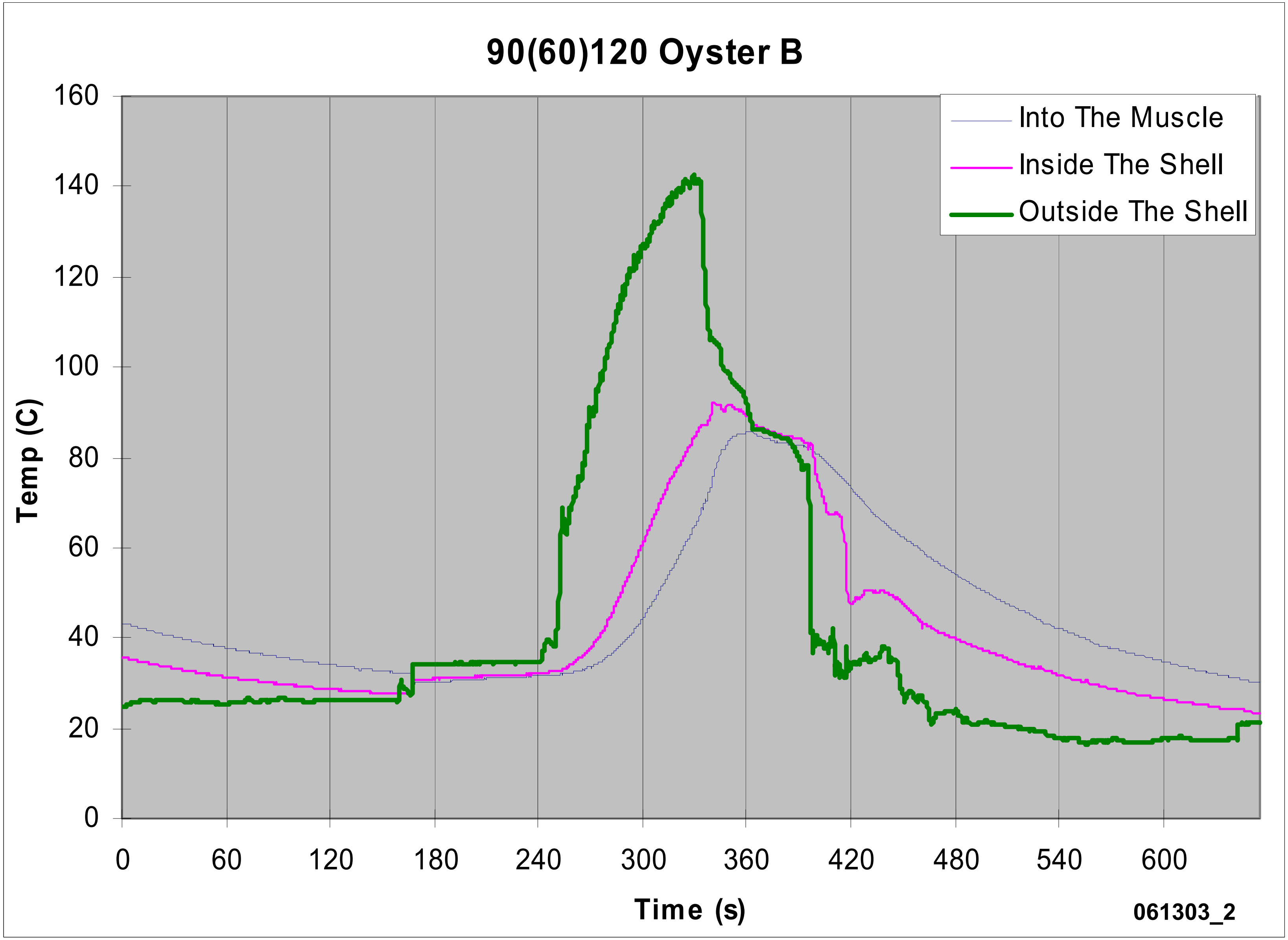
90(60)120 Oyster B
Into The Muscle
Inside The Shell
Outside The Shell
Temp (C)
160
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120
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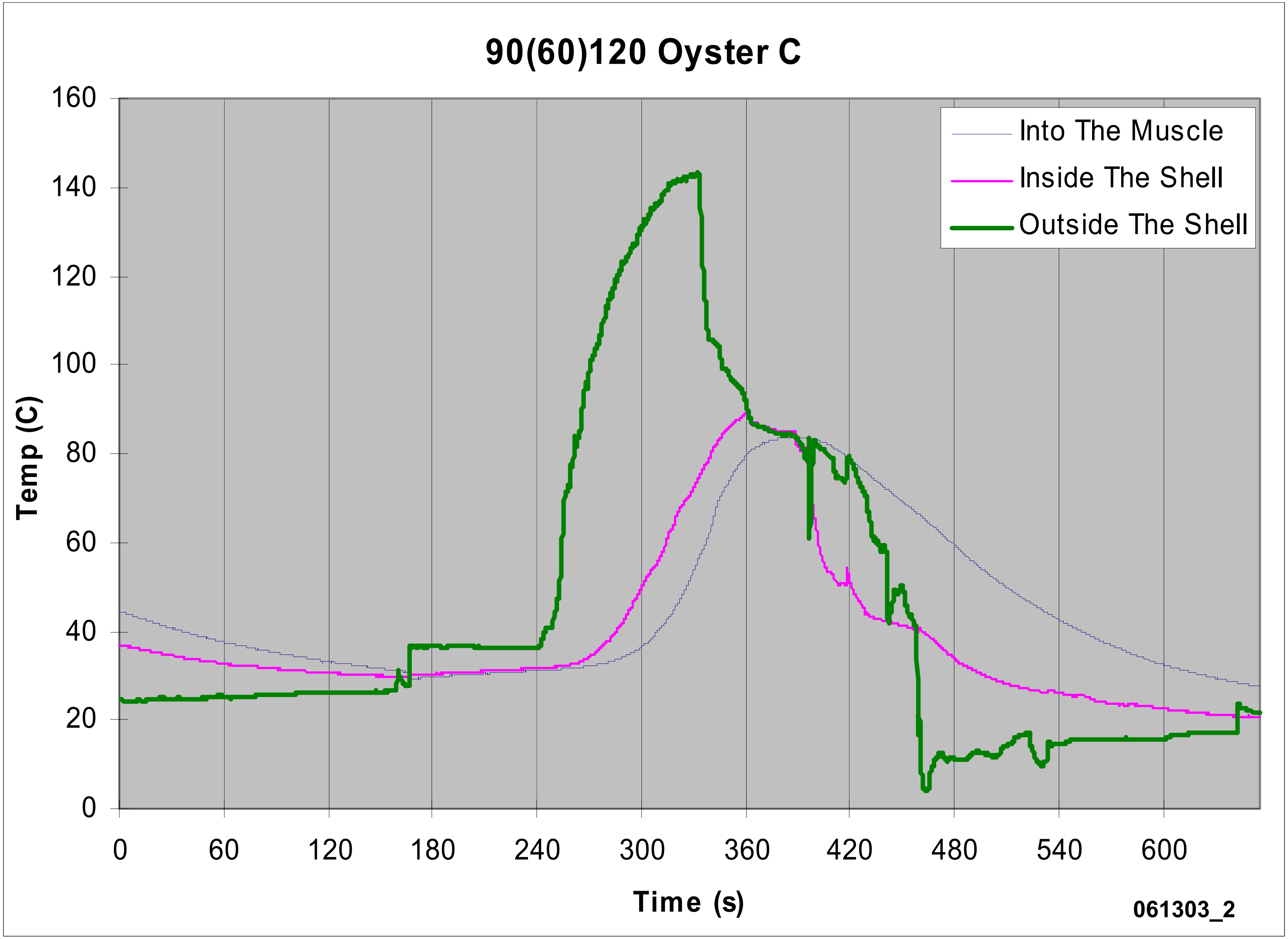
600
Time (s)
061303_2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Temp (C)
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420
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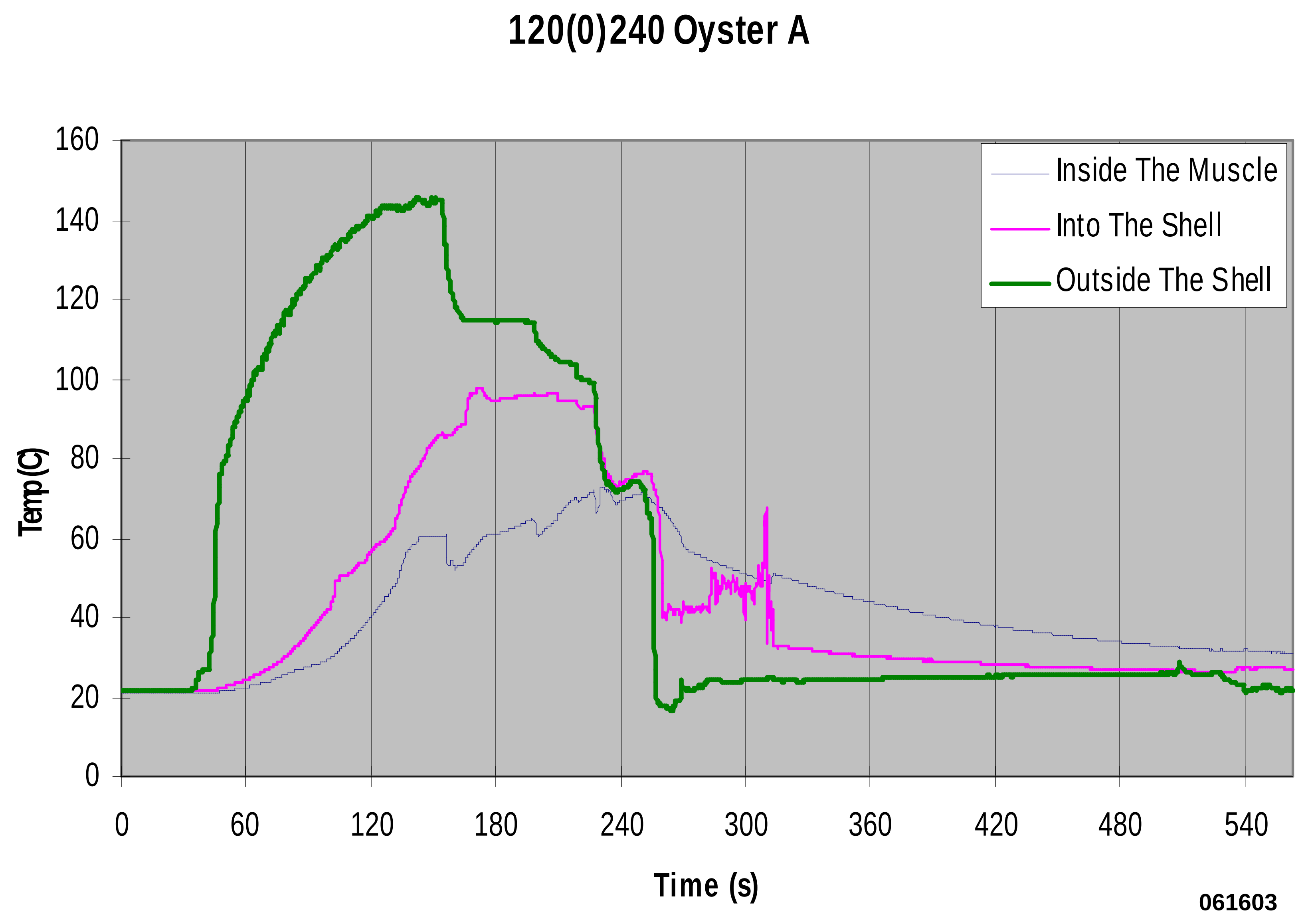
600
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
061303_2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Temp (C)
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420
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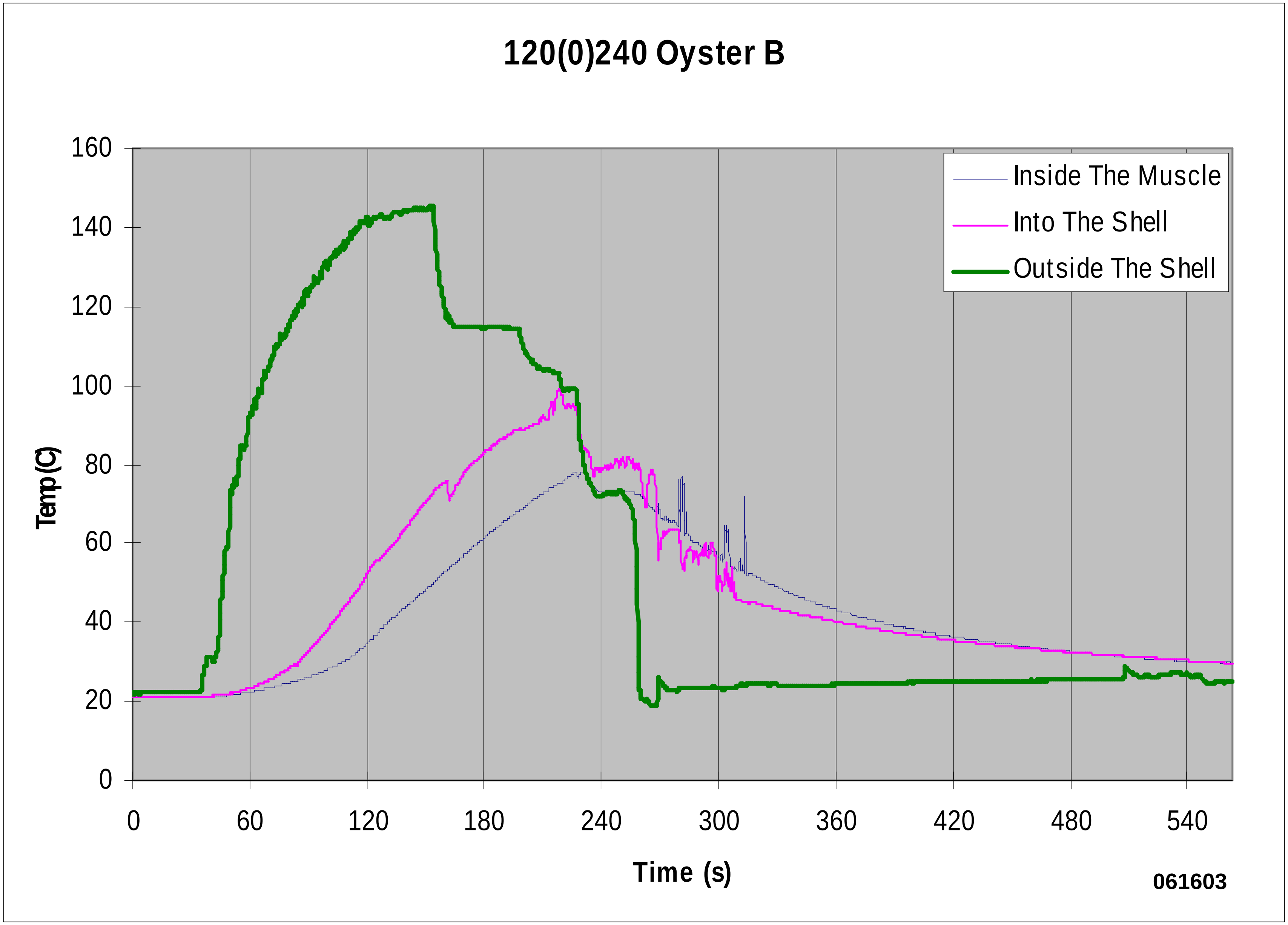
540
Time (s)
Inside The Muscle
Into The Shell
Outside The Shell
061603


120(0)240 Oyster B
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Temp (C)
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420
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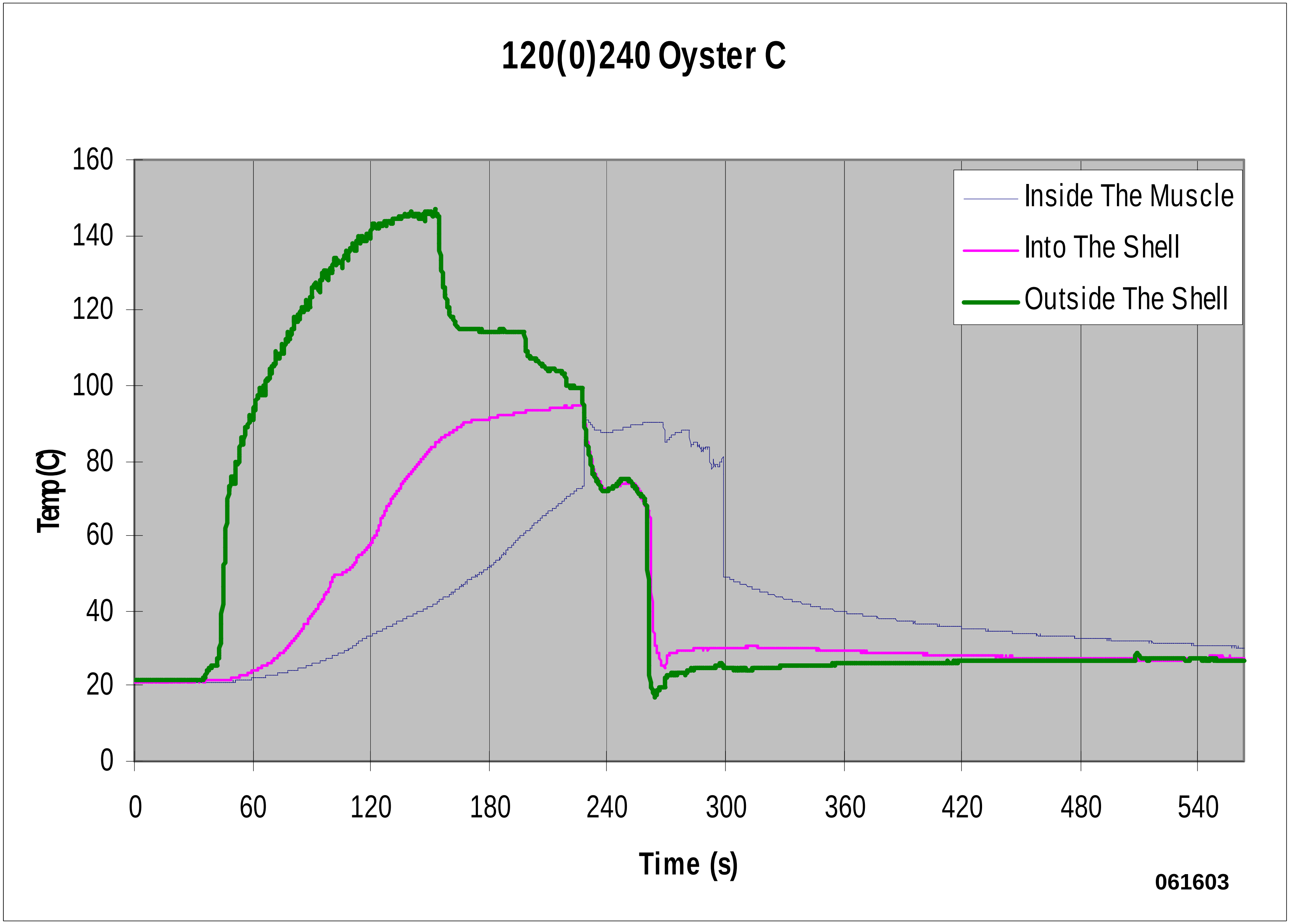
540
Time (s)
Inside The Muscle
Into The Shell
Outside The Shell
061603


120(0)240 Oyster C
Temp(C)
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120
180
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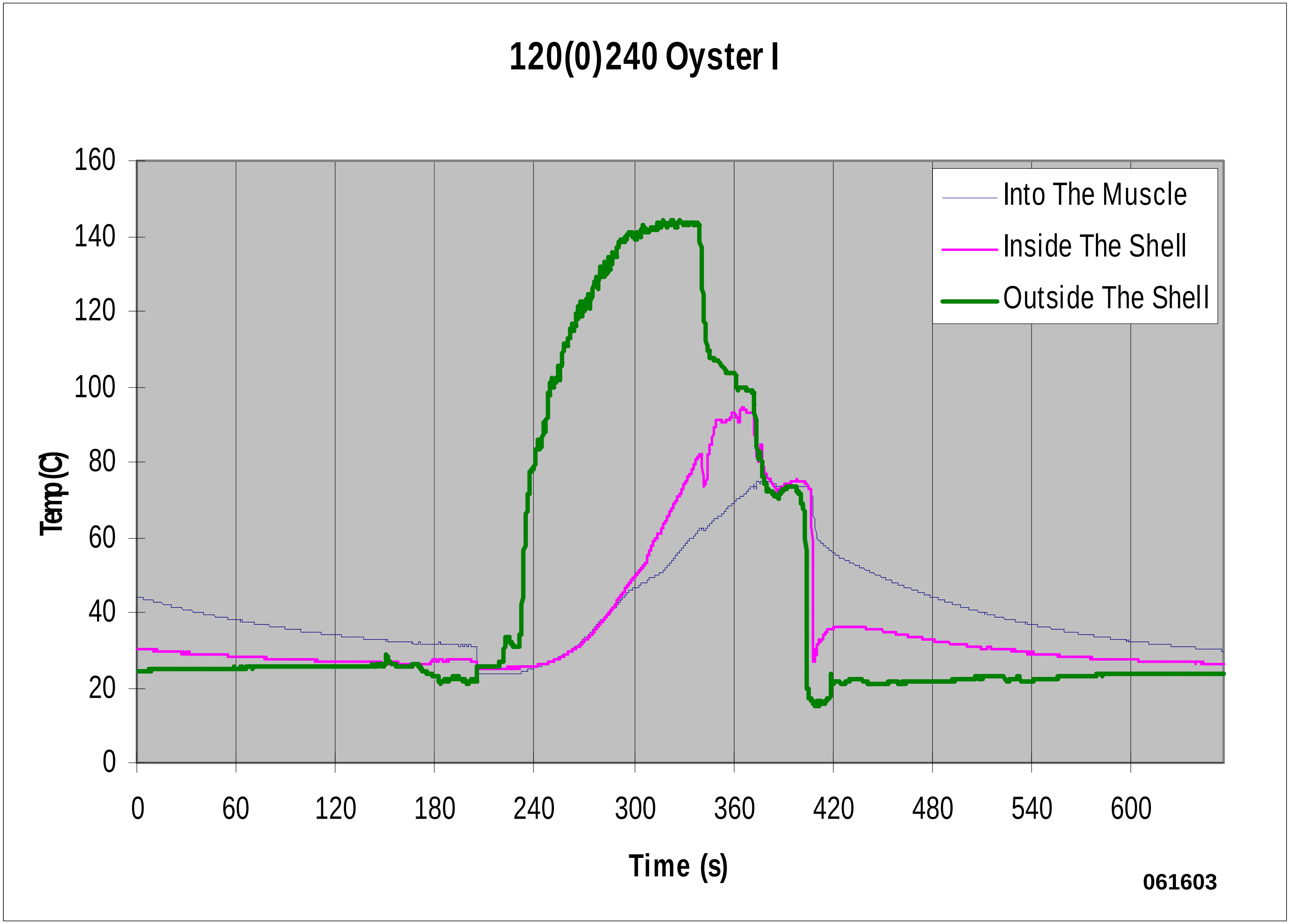
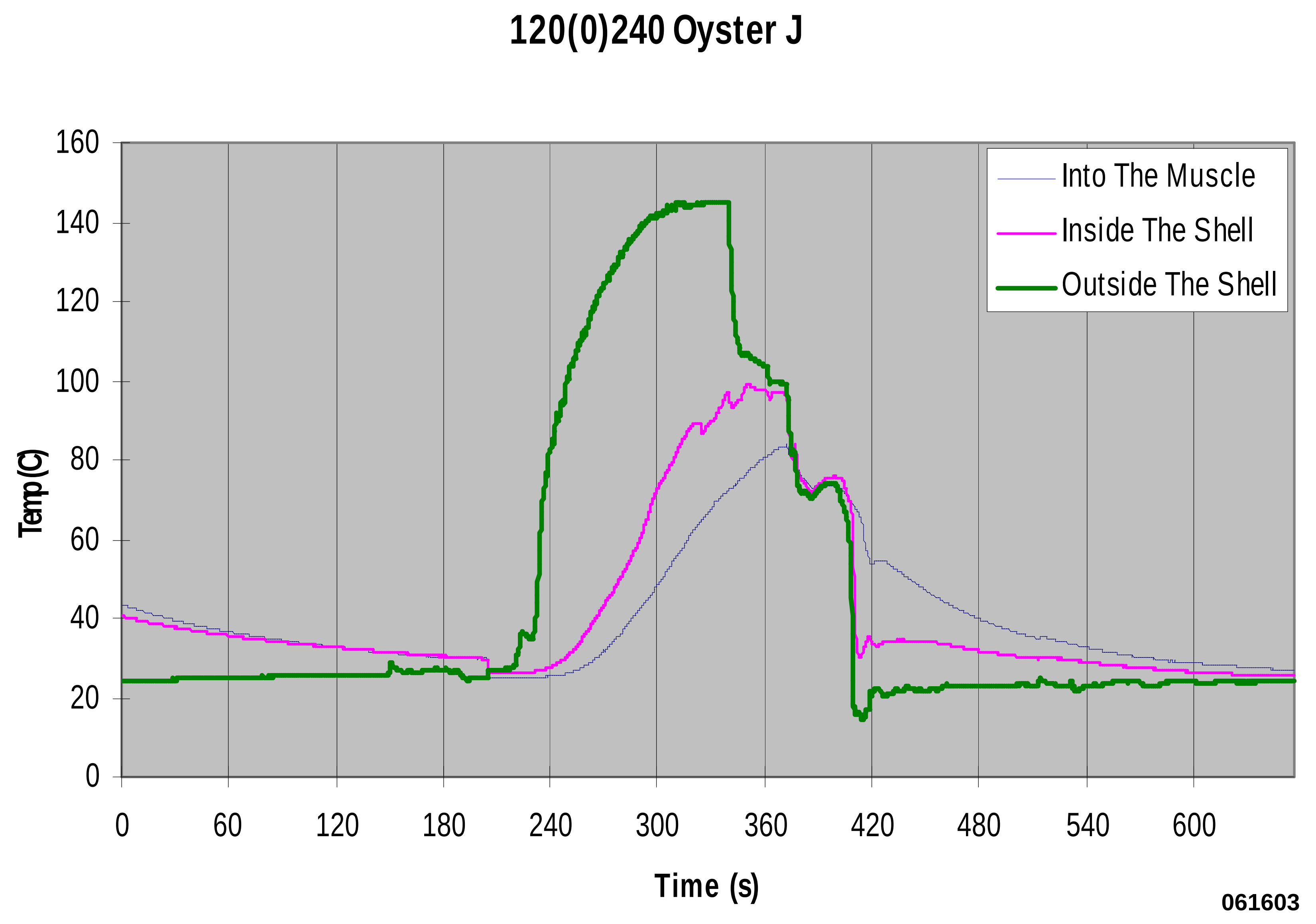
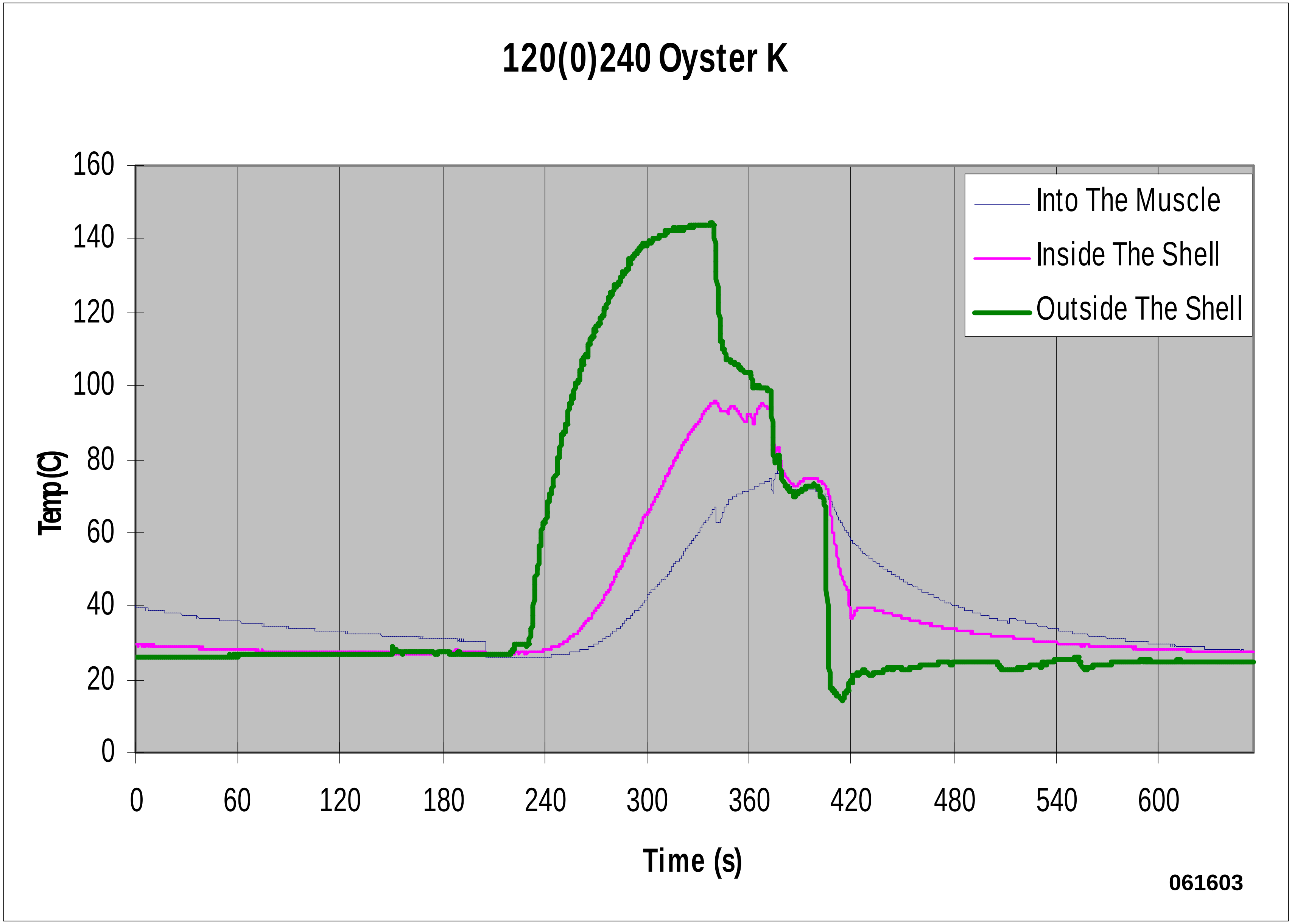
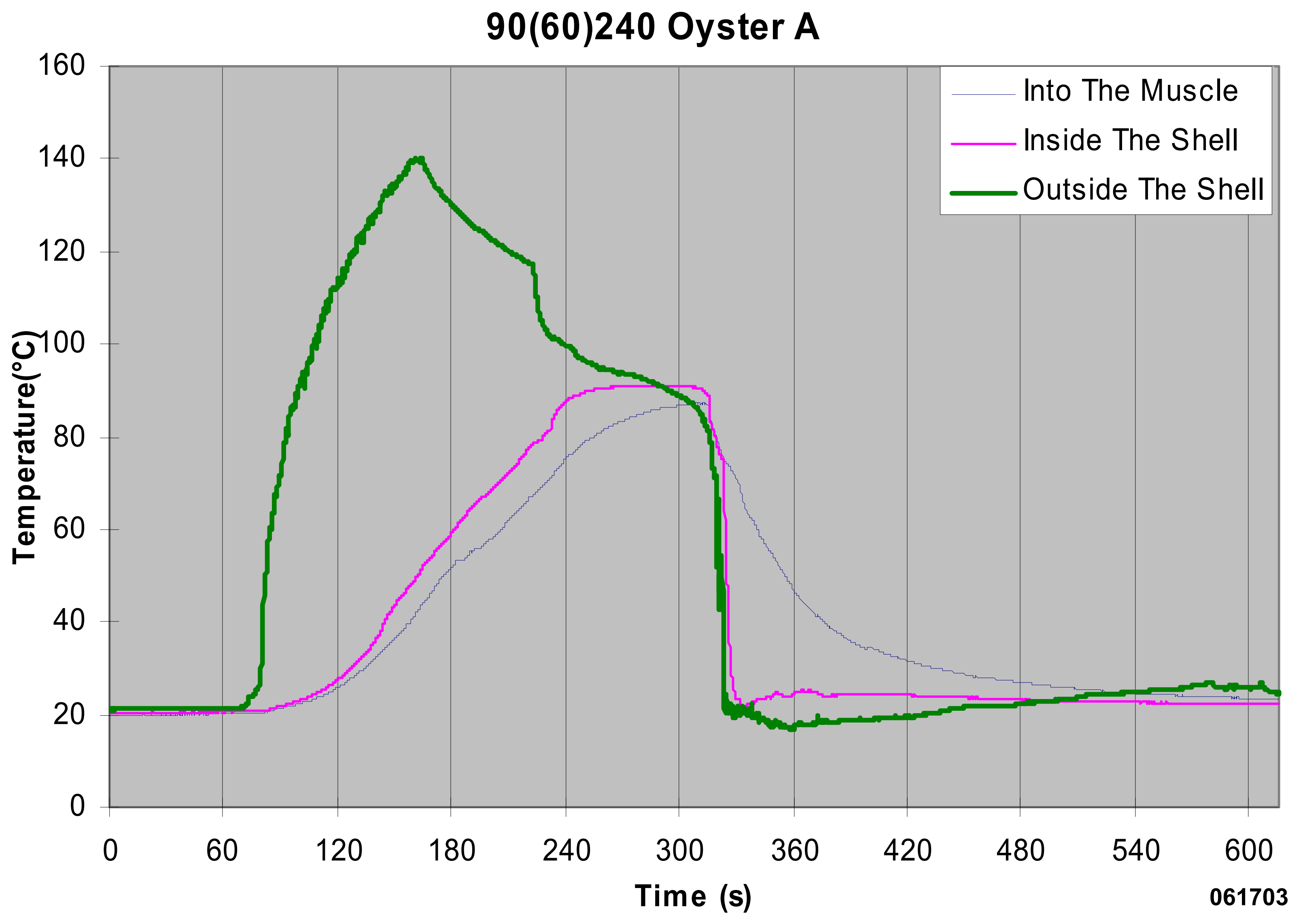
540
Time (s)
Inside The Muscle
Into The Shell
Outside The Shell
061603

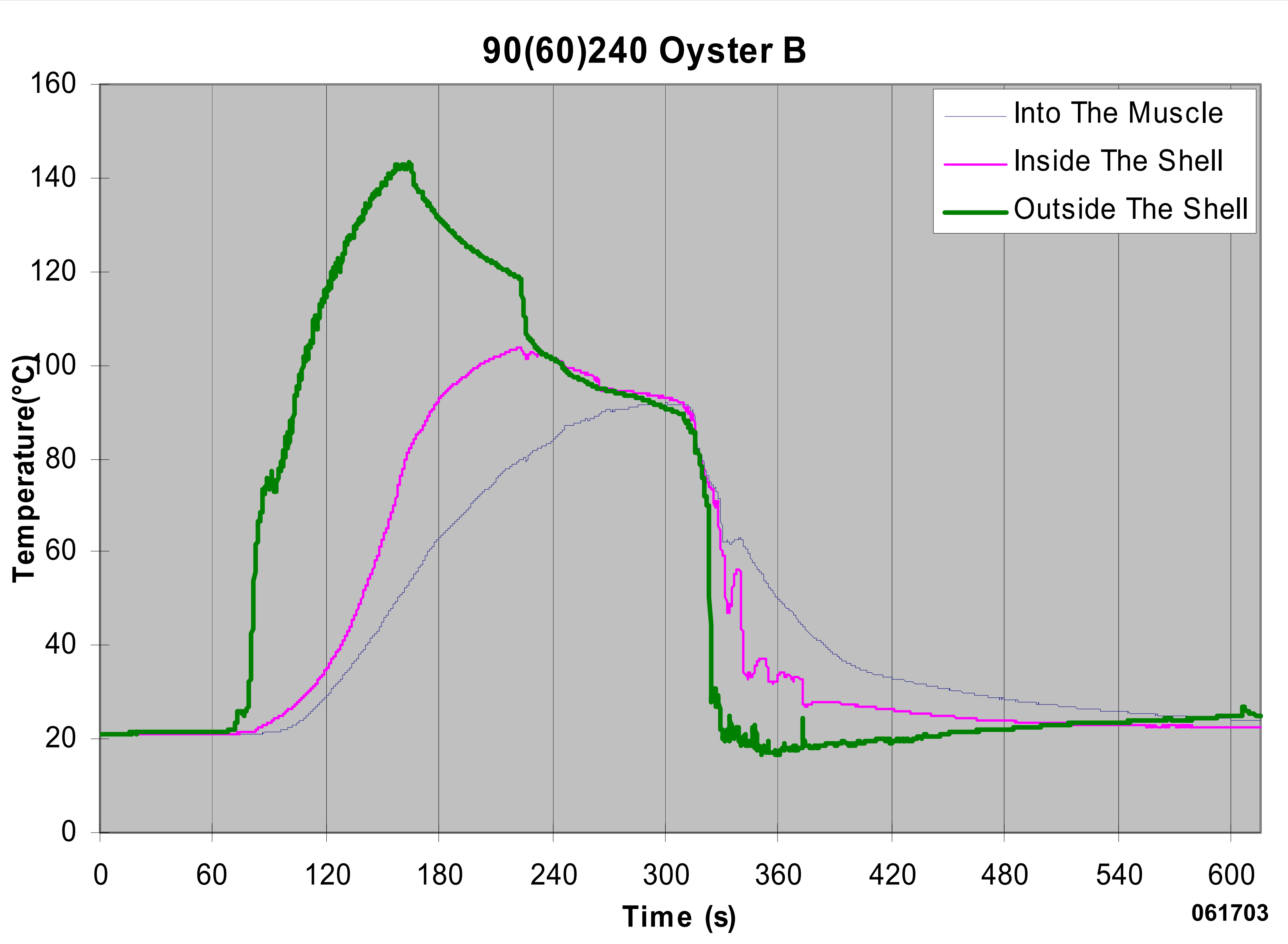


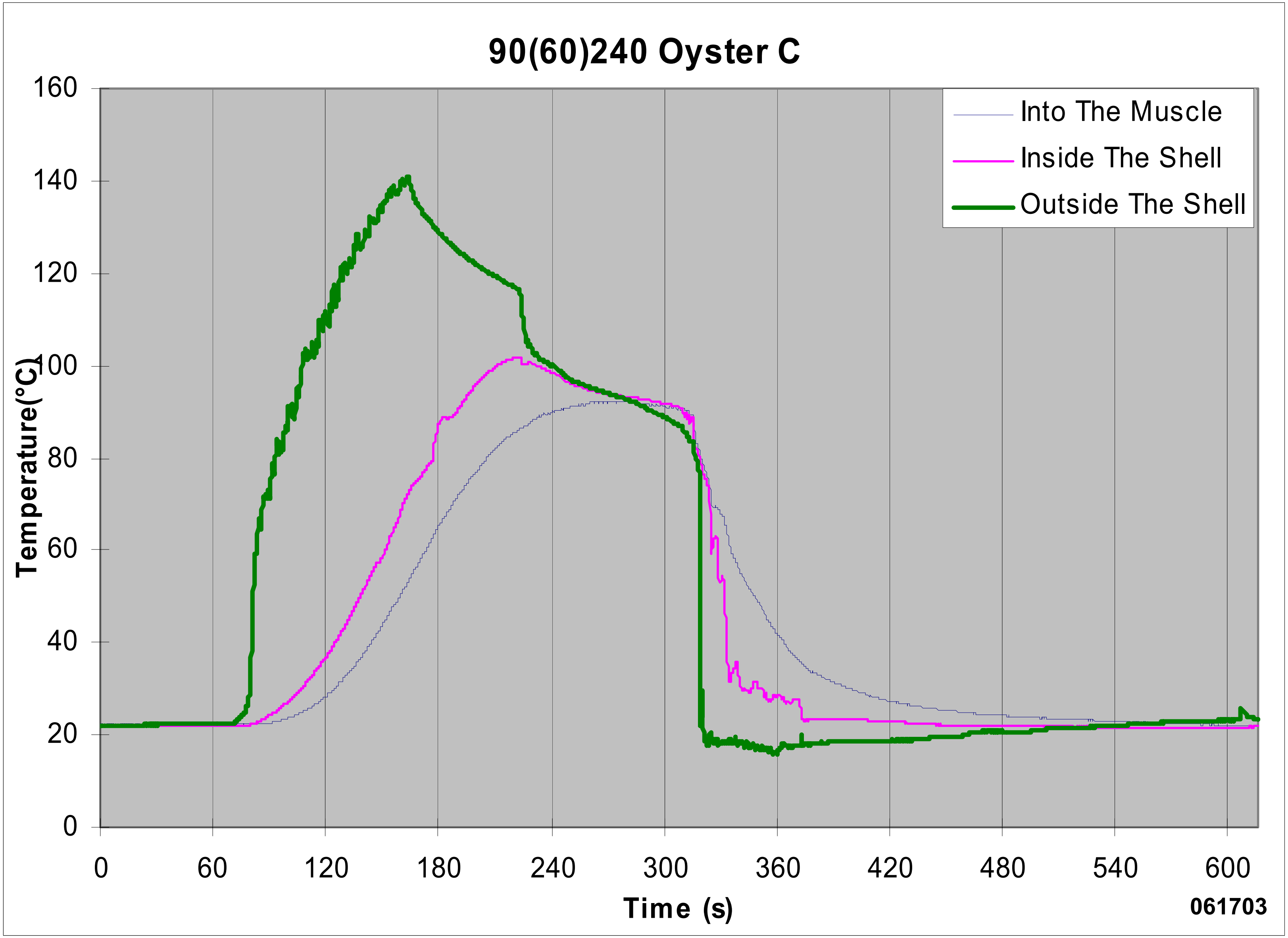
120(0)240 Oyster I

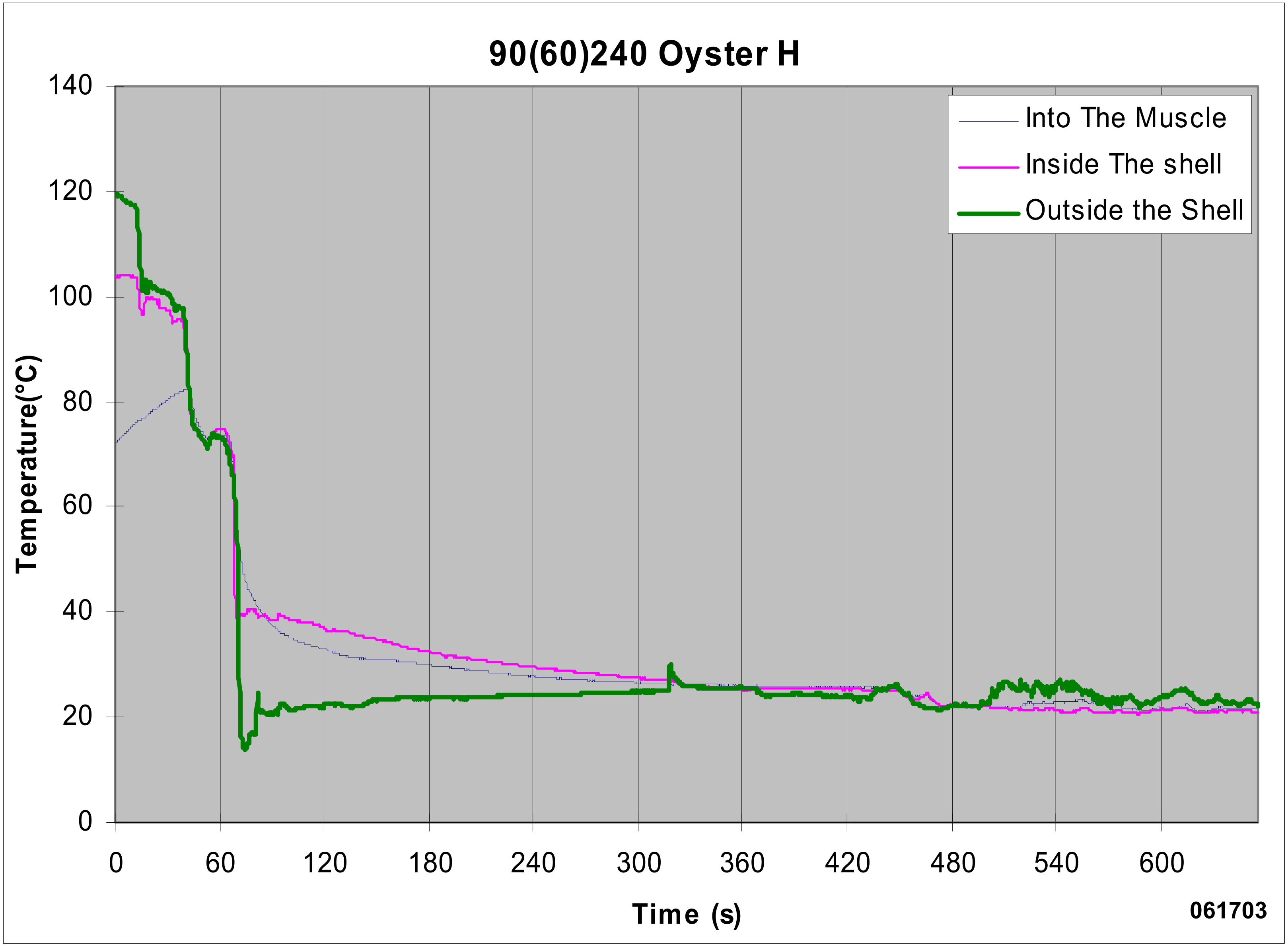

120(0)240 Oyster J
Temp (C)
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
061603

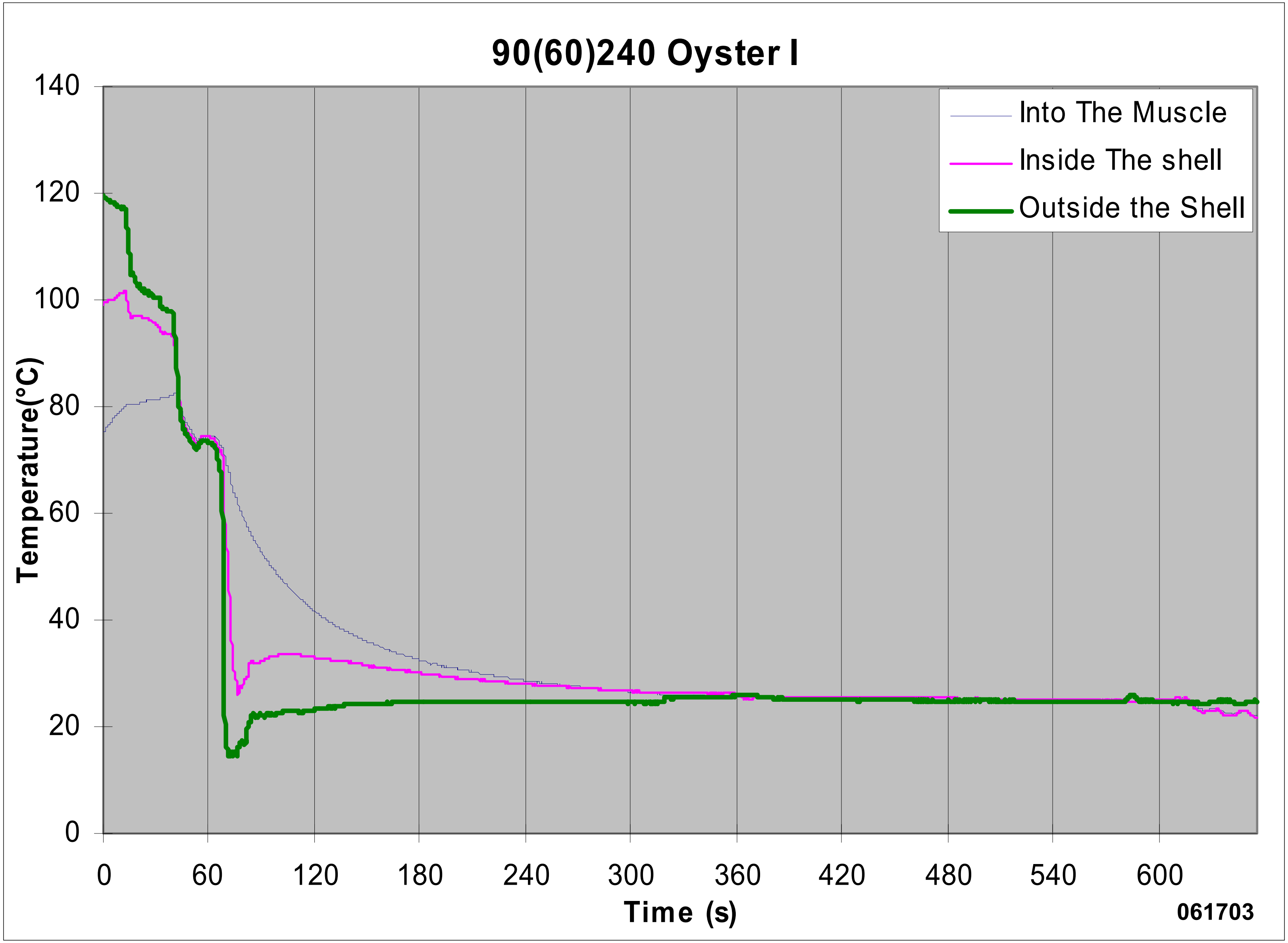

120(0)240 Oyster K
Temp(C)
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
061603

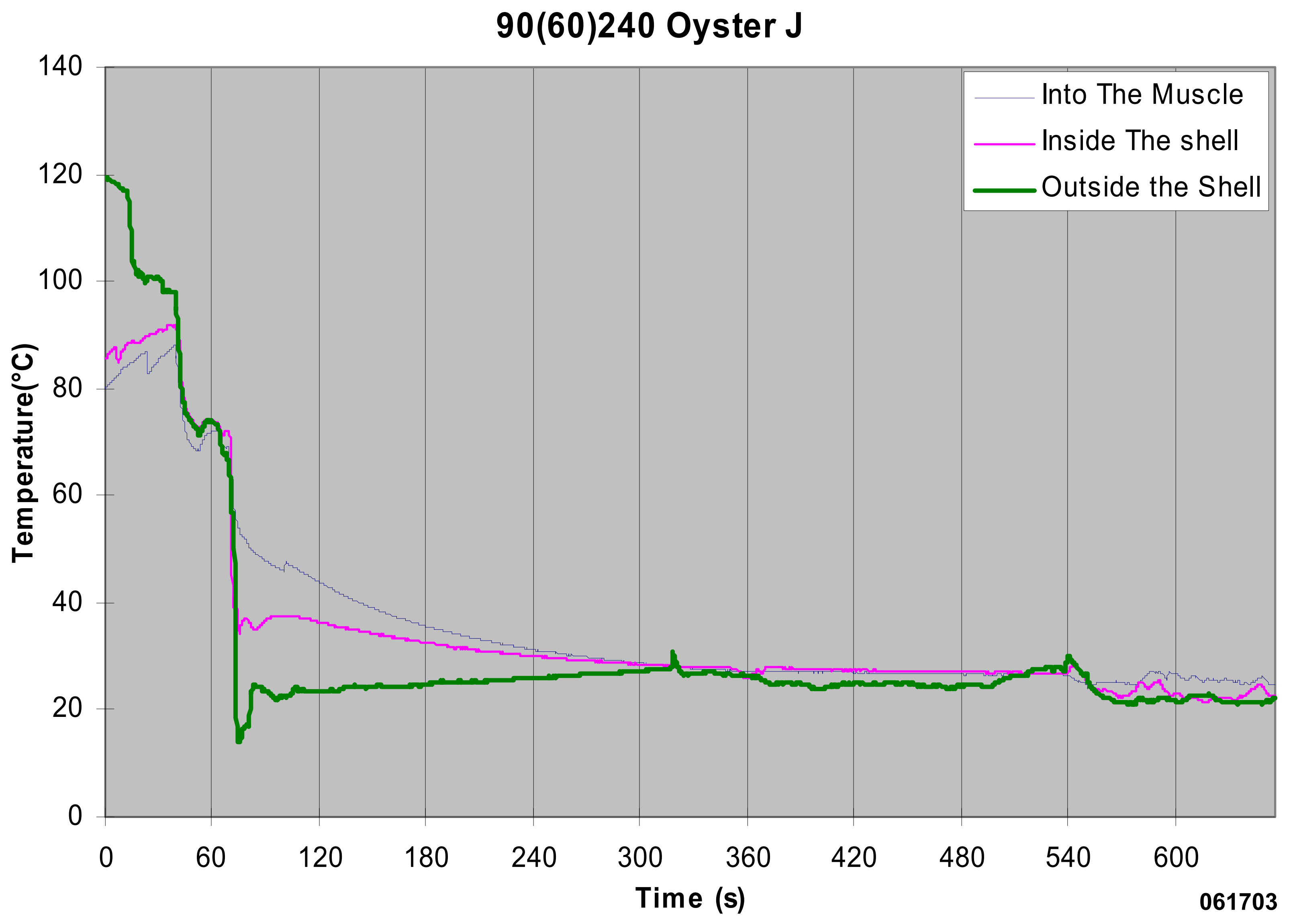

90(60)240 Oyster A
Temperature(°C)
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
061703

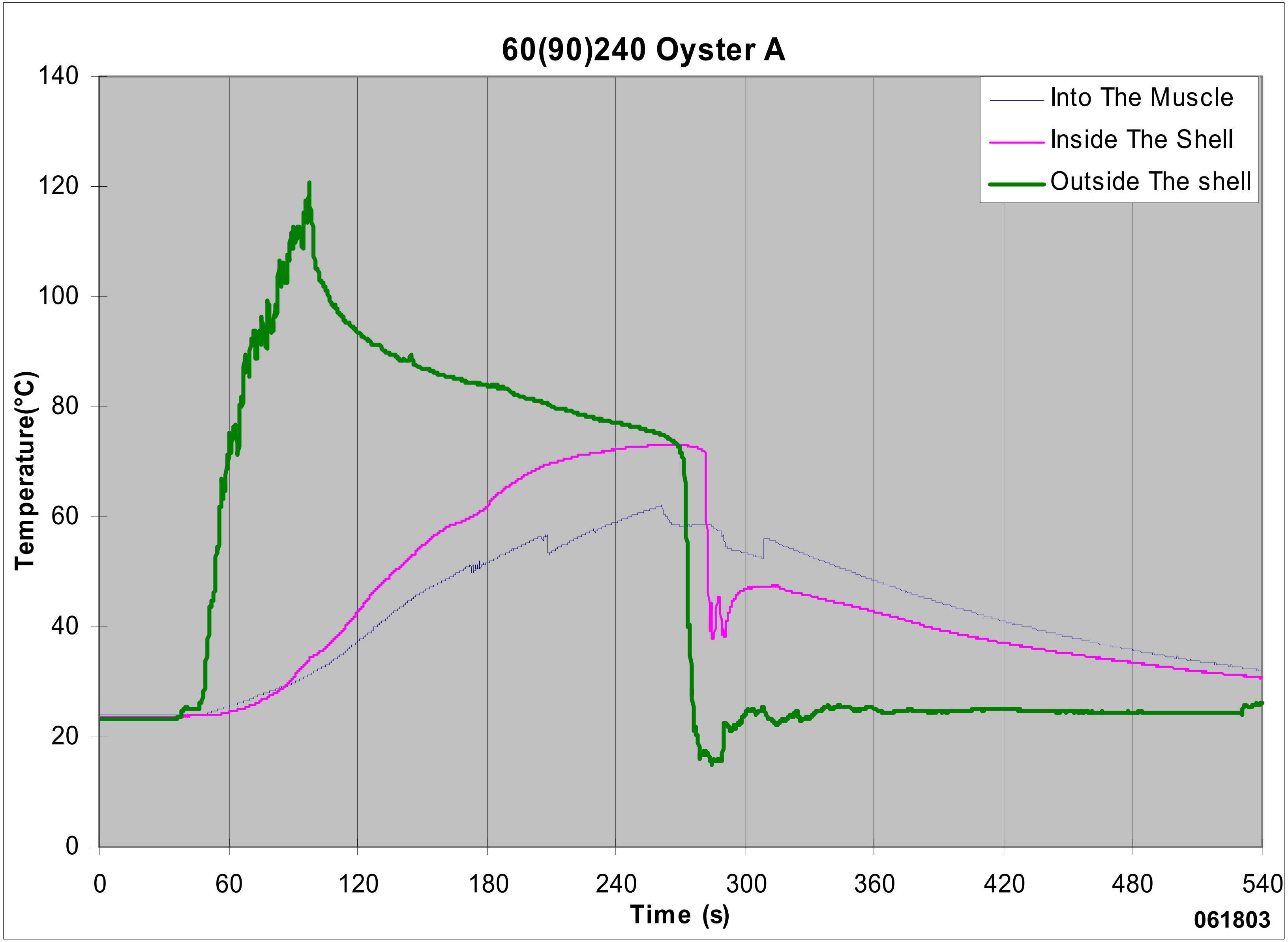

90(60)240 Oyster B
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
061703

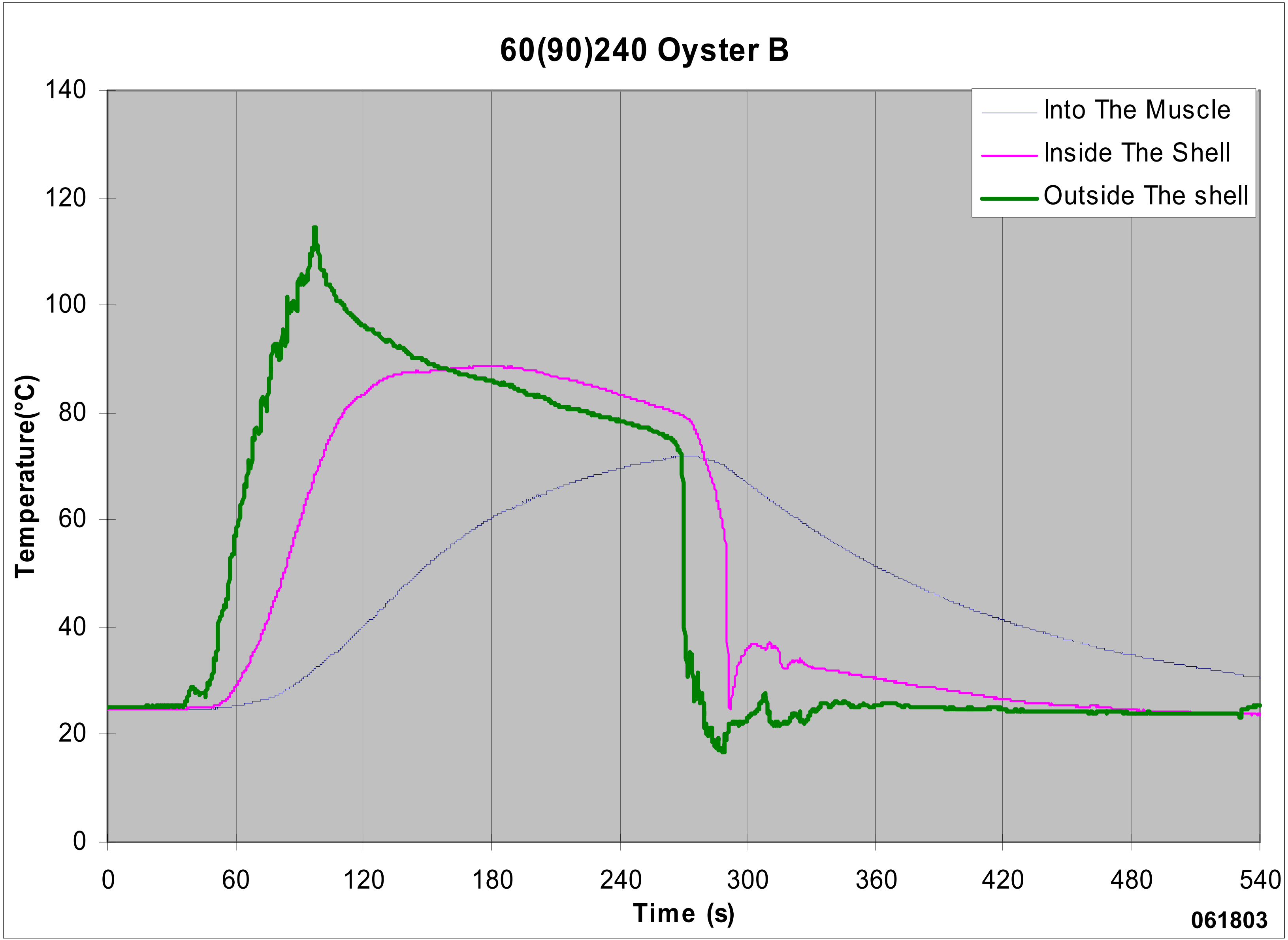

90(60)240 Oyster C
Temperature(°C)
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
061703
Into The Muscle
Inside The Shell
Outside The Shell

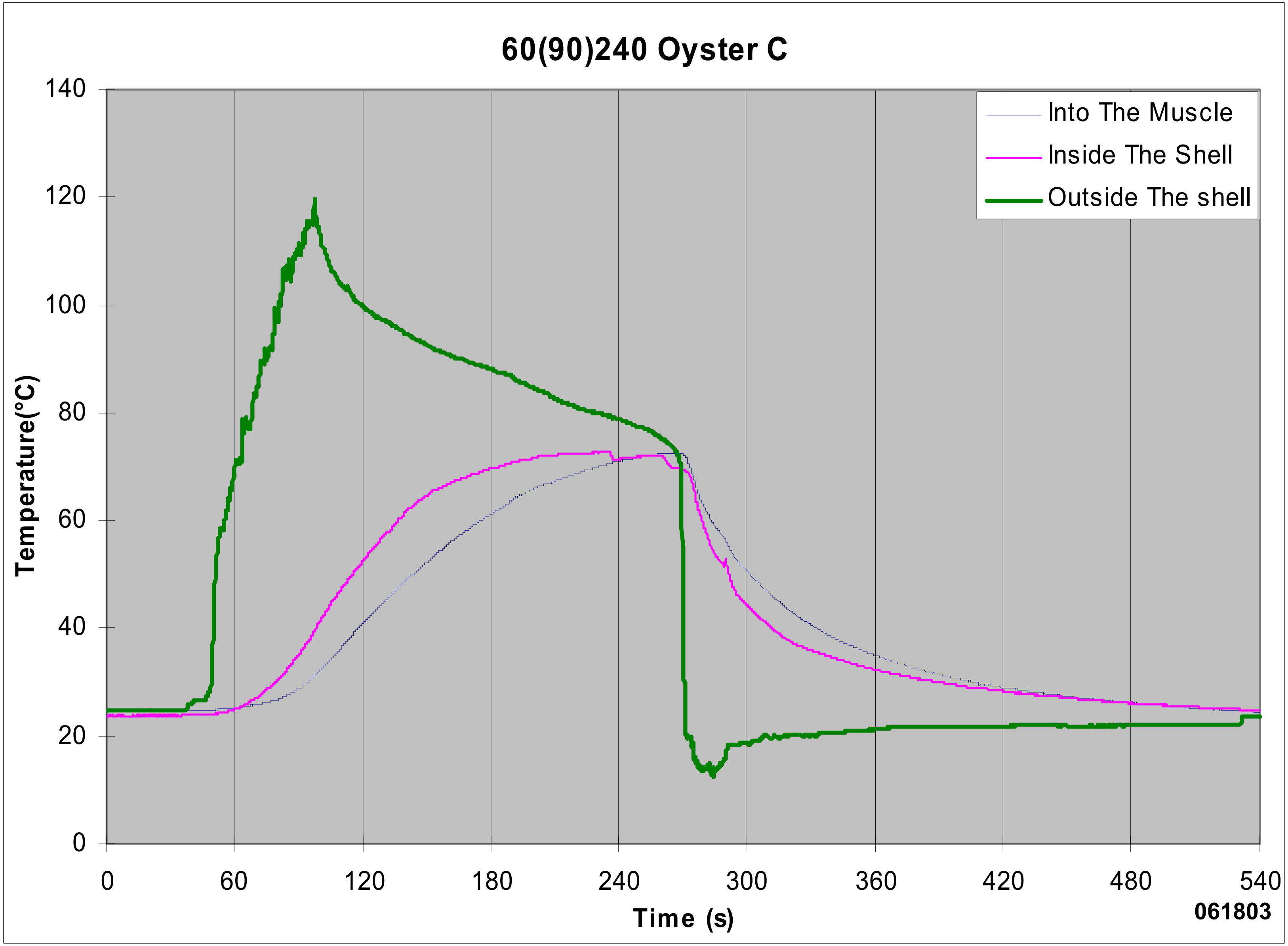

90(60)240 Oyster H
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside The shell
Outside the Shell
061703

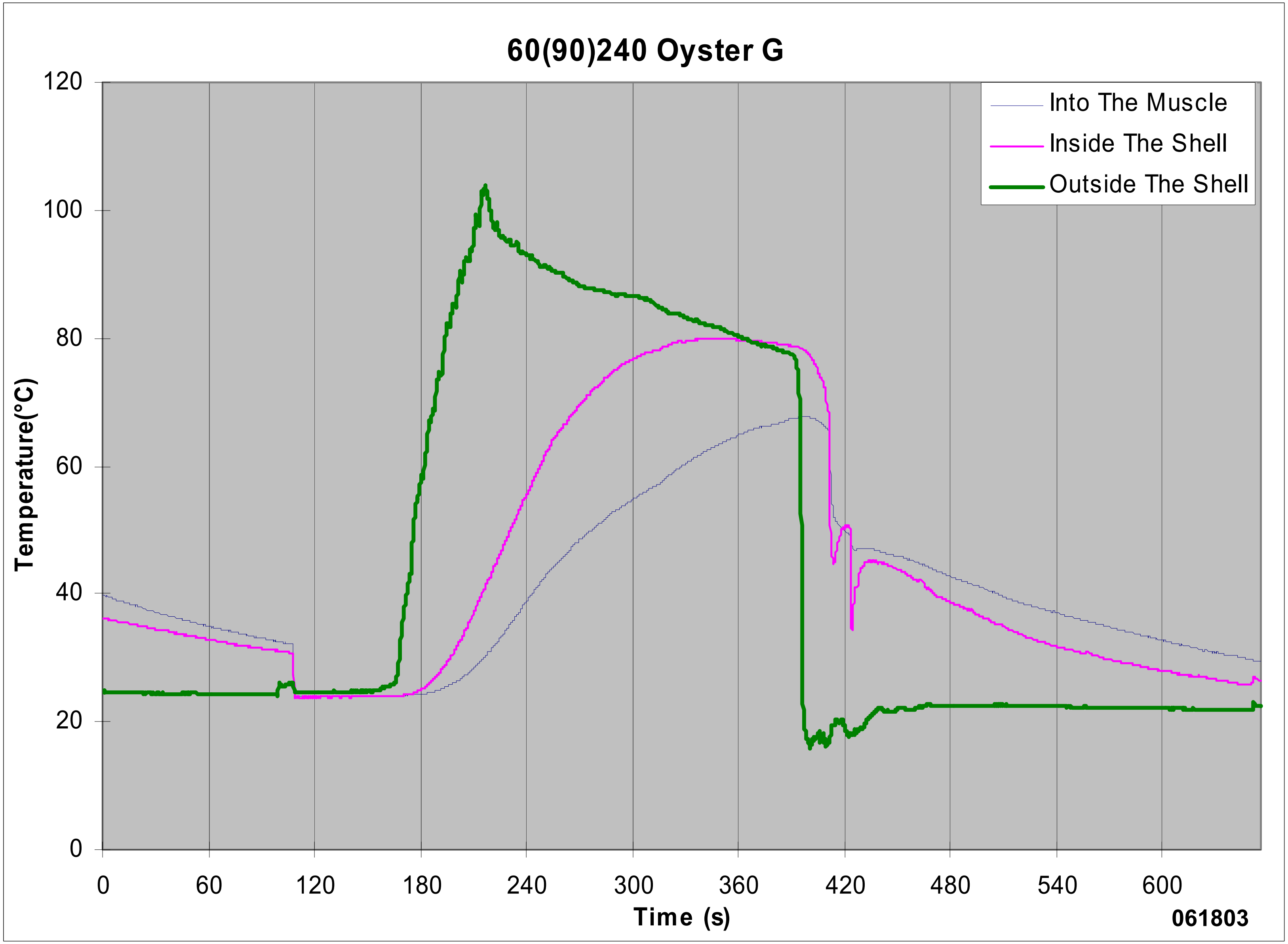

90(60)240 Oyster I
Into The Muscle
Inside The shell
Outside the Shell
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
061703

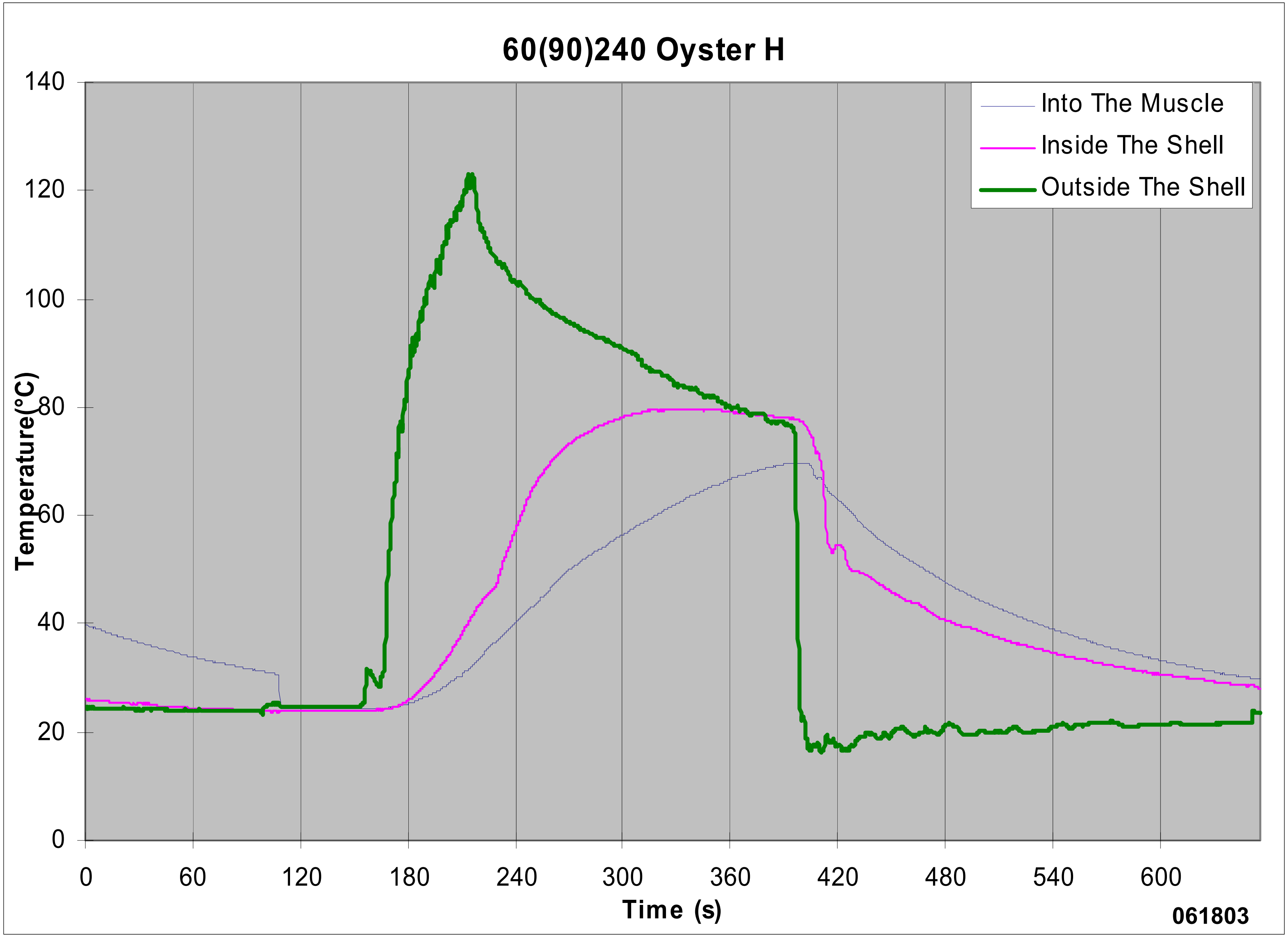

90(60)240 Oyster J
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside The shell
Outside the Shell
061703

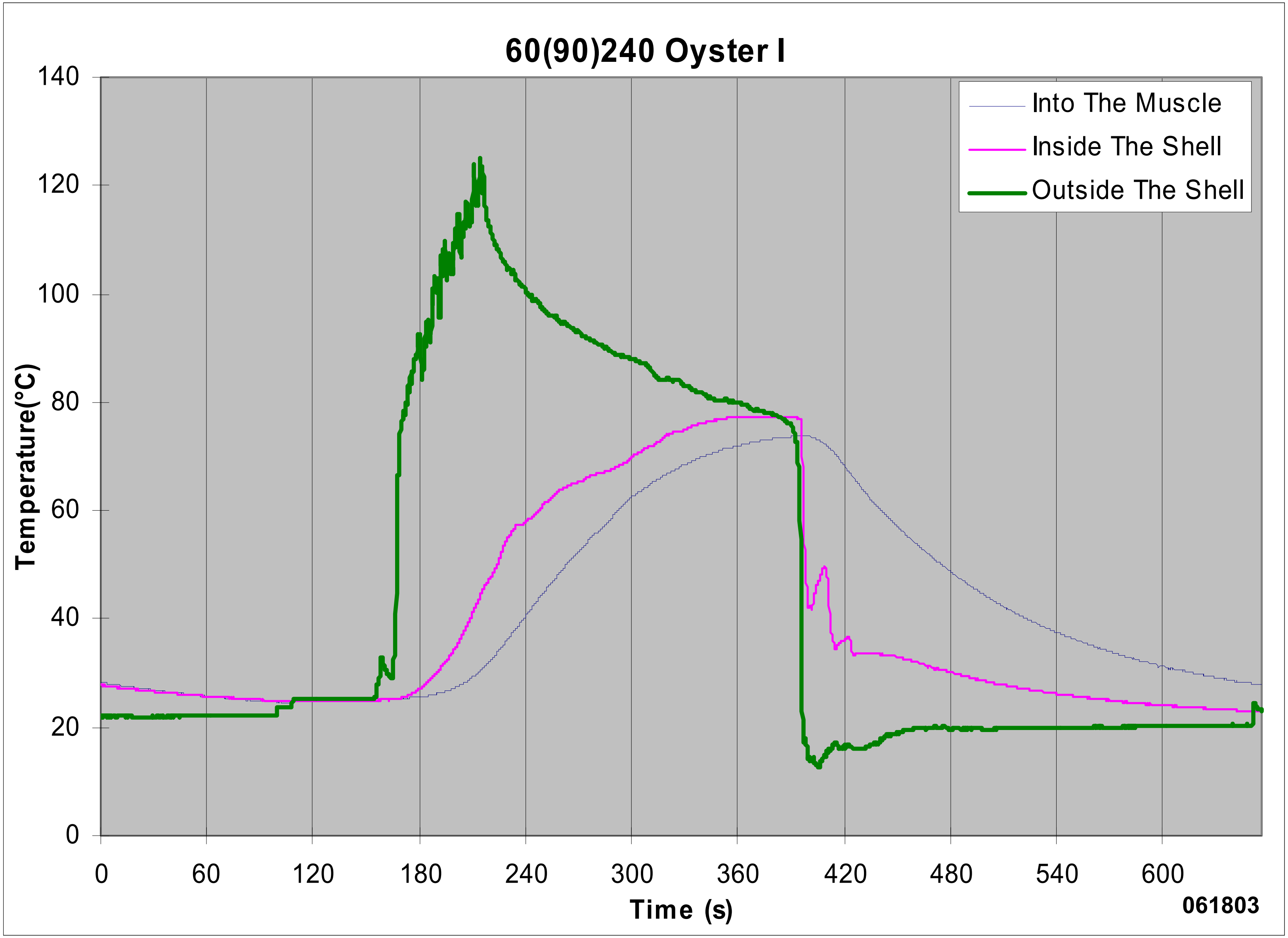

60(90)240 Oyster A
Temperature(°C)
0
20
40
60
80
100
120
140
Time (s)
0
60
120
180
240
300
360
420
480
540
Into The Muscle
Inside The Shell
Outside The shell
061803

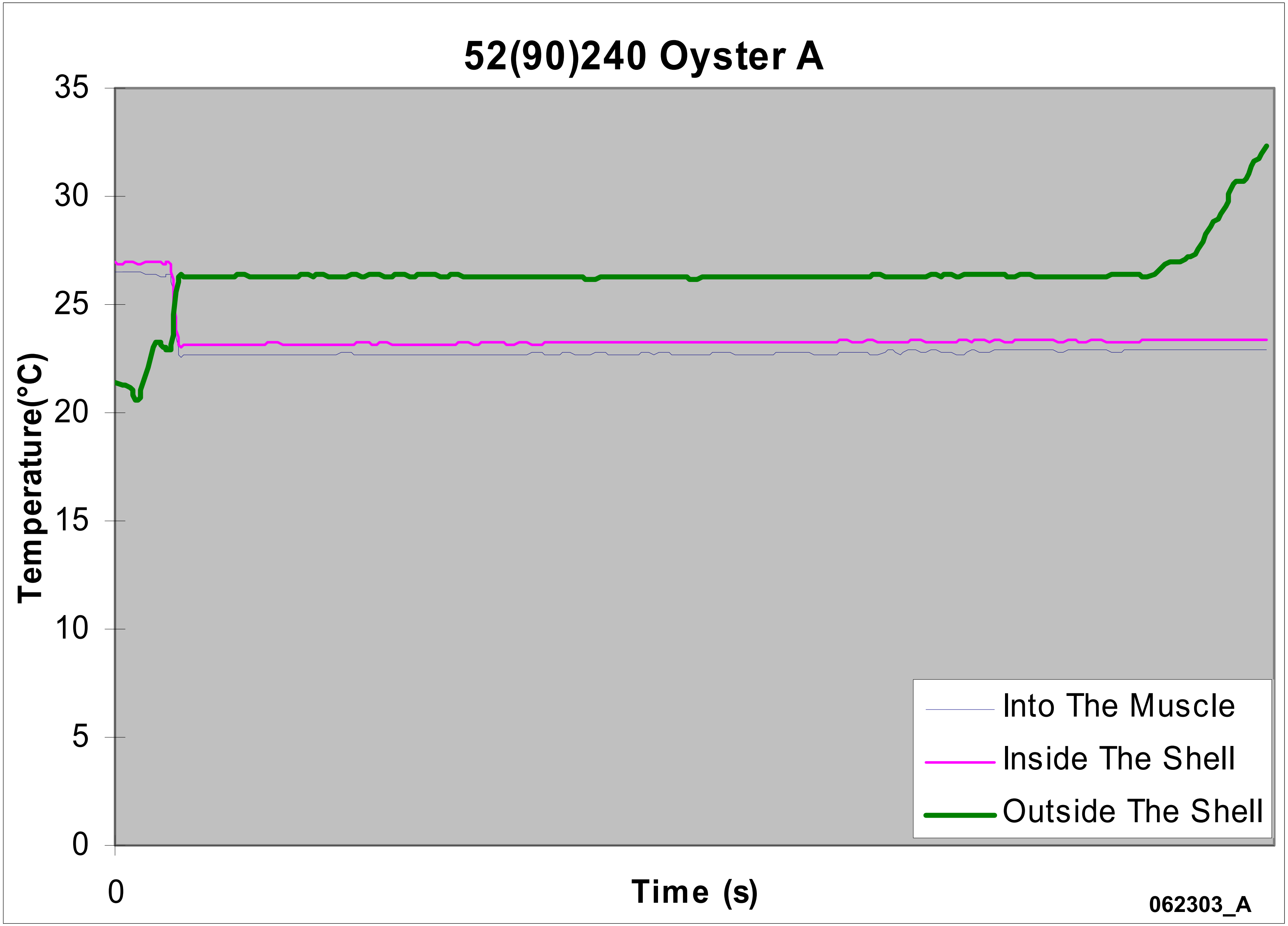

60(90)240 Oyster B
Into The Muscle
Inside The Shell
Outside The shell
Temperature(°C)
0
20
40
60
80
100
120
140
0
60
120
180
240
300
360
420
480
540
Time (s)
061803

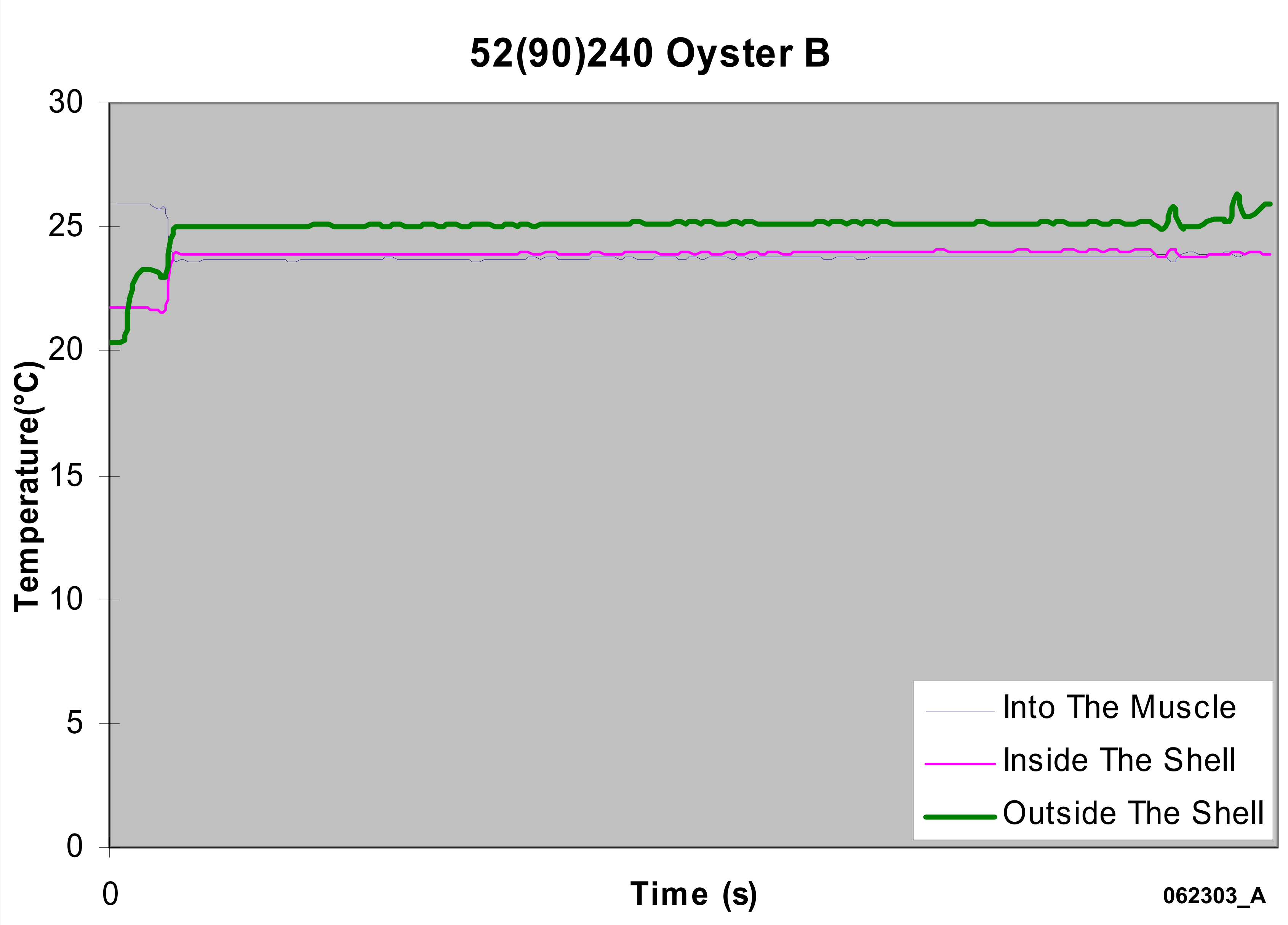

60(90)240 Oyster C
Into The Muscle
Inside The Shell
Outside The shell
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
061803

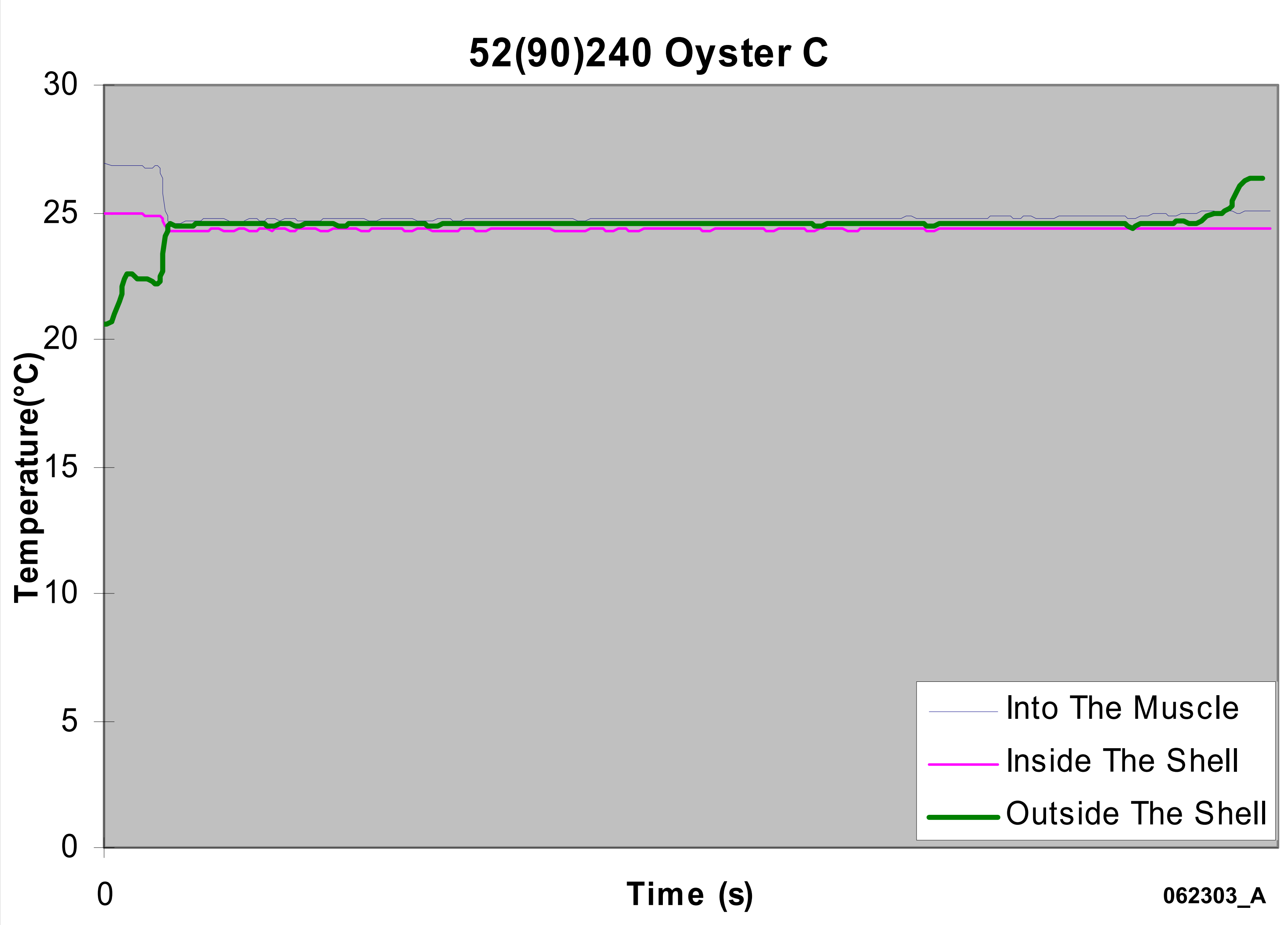

60(90)240 Oyster G
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
061803

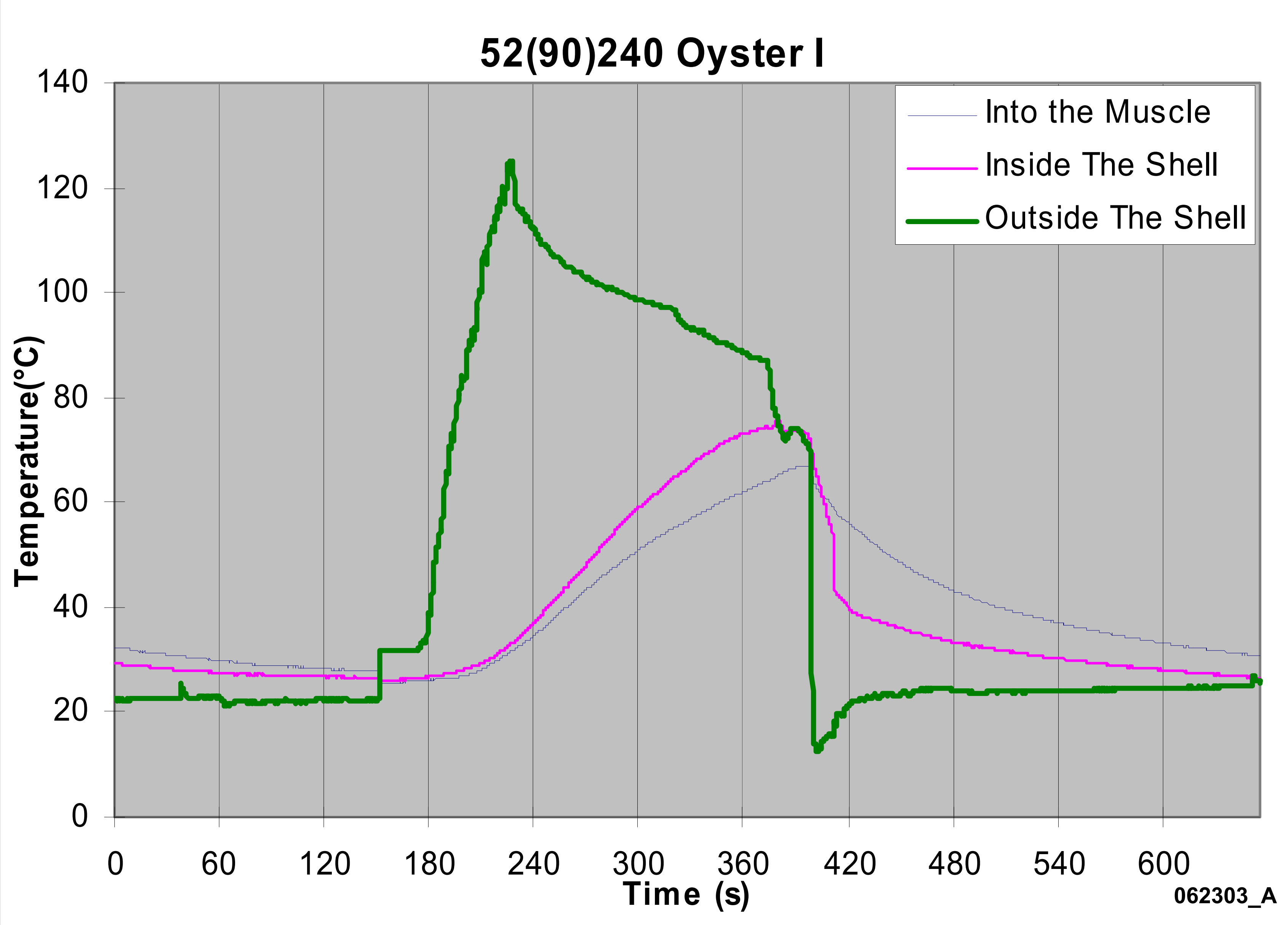

60(90)240 Oyster H
Temperature (°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
061803


60(90)240 Oyster I
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
140
0
60
120
180
240
300
360
420
480
540
600
Time (s)
061803


52(90)240 Oyster A
Temperature(°C)
35
30
25
20
15
10
5
0
0
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
062303_A


52(90)240 Oyster B
Temperature(°C)
30
25
20
15
10
5
0
0
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
062303_A


52(90)240 Oyster C
Temperature(°C)
30
25
20
15
10
5
0
0
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
062303_A


52(90)240 Oyster I
Into the Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
140
Time (s)
0
60
120
180
240
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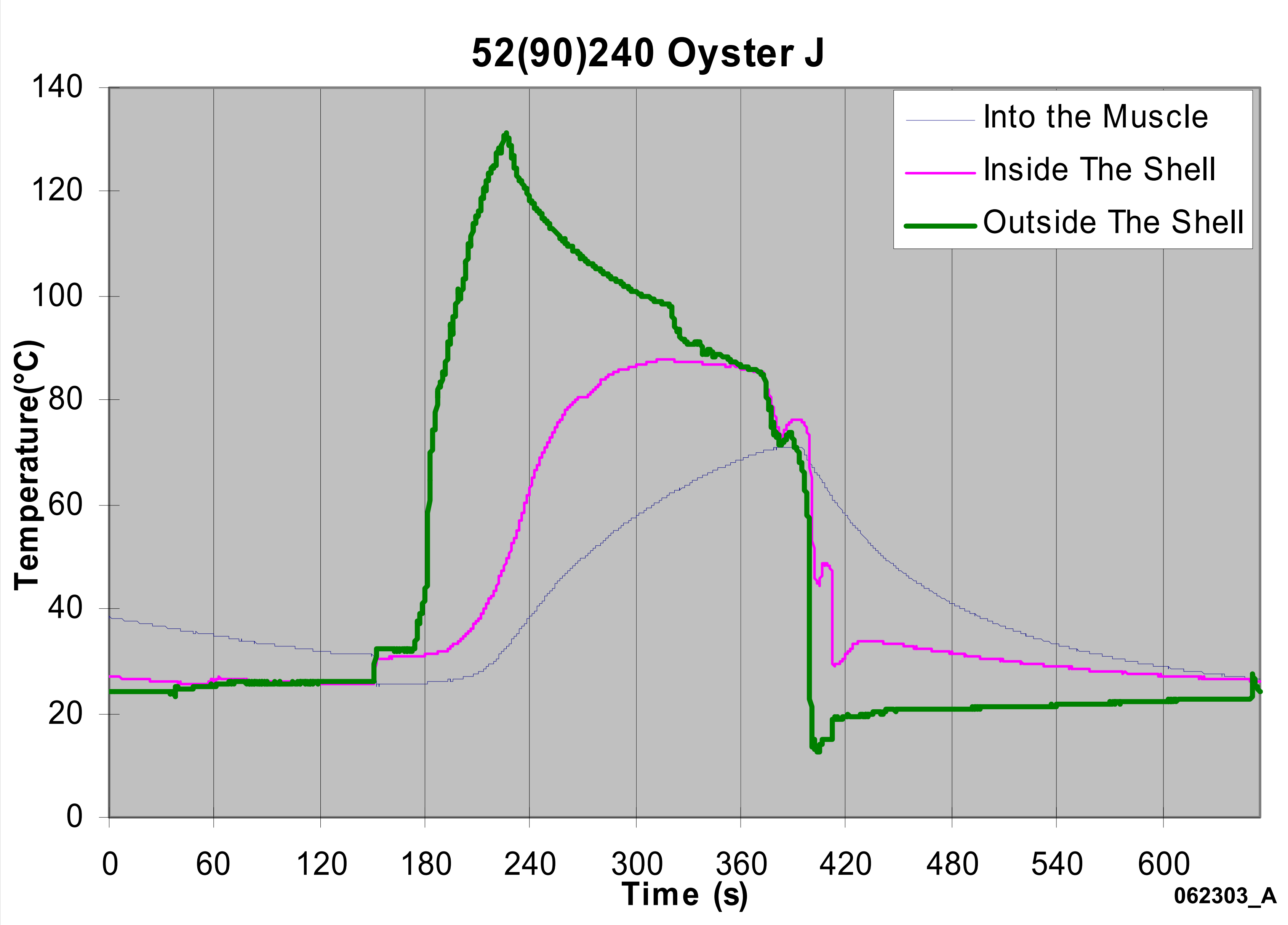
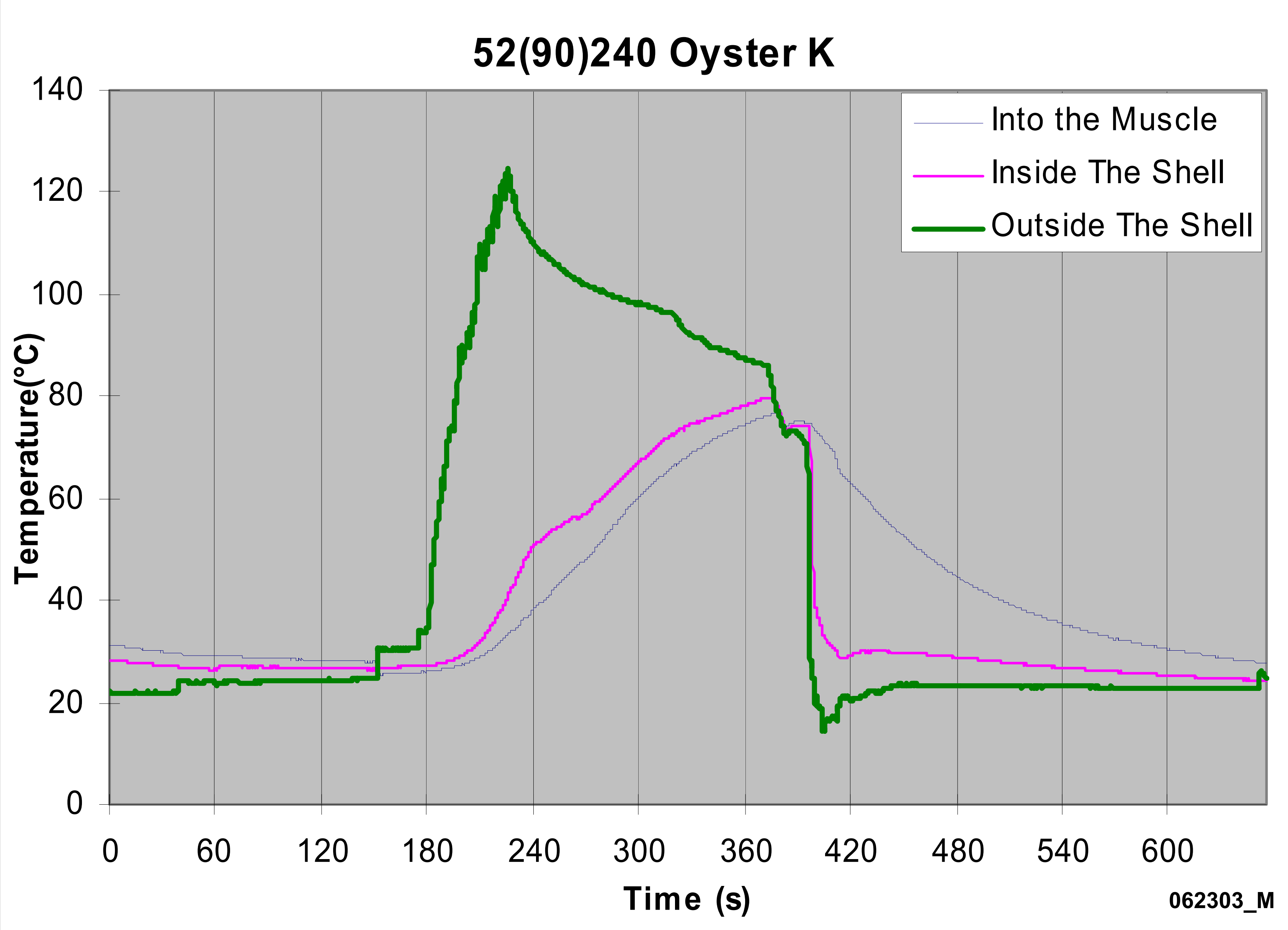
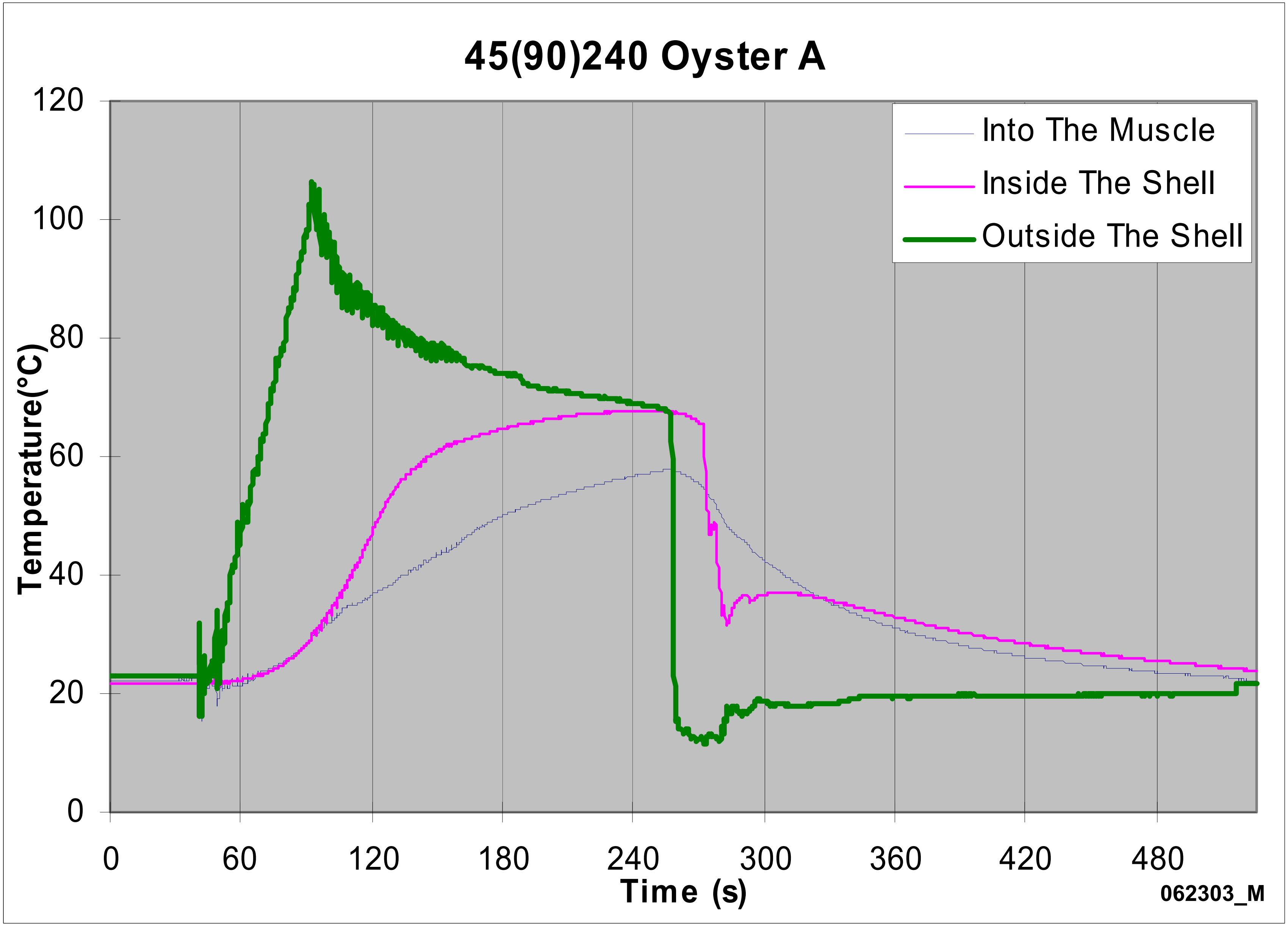
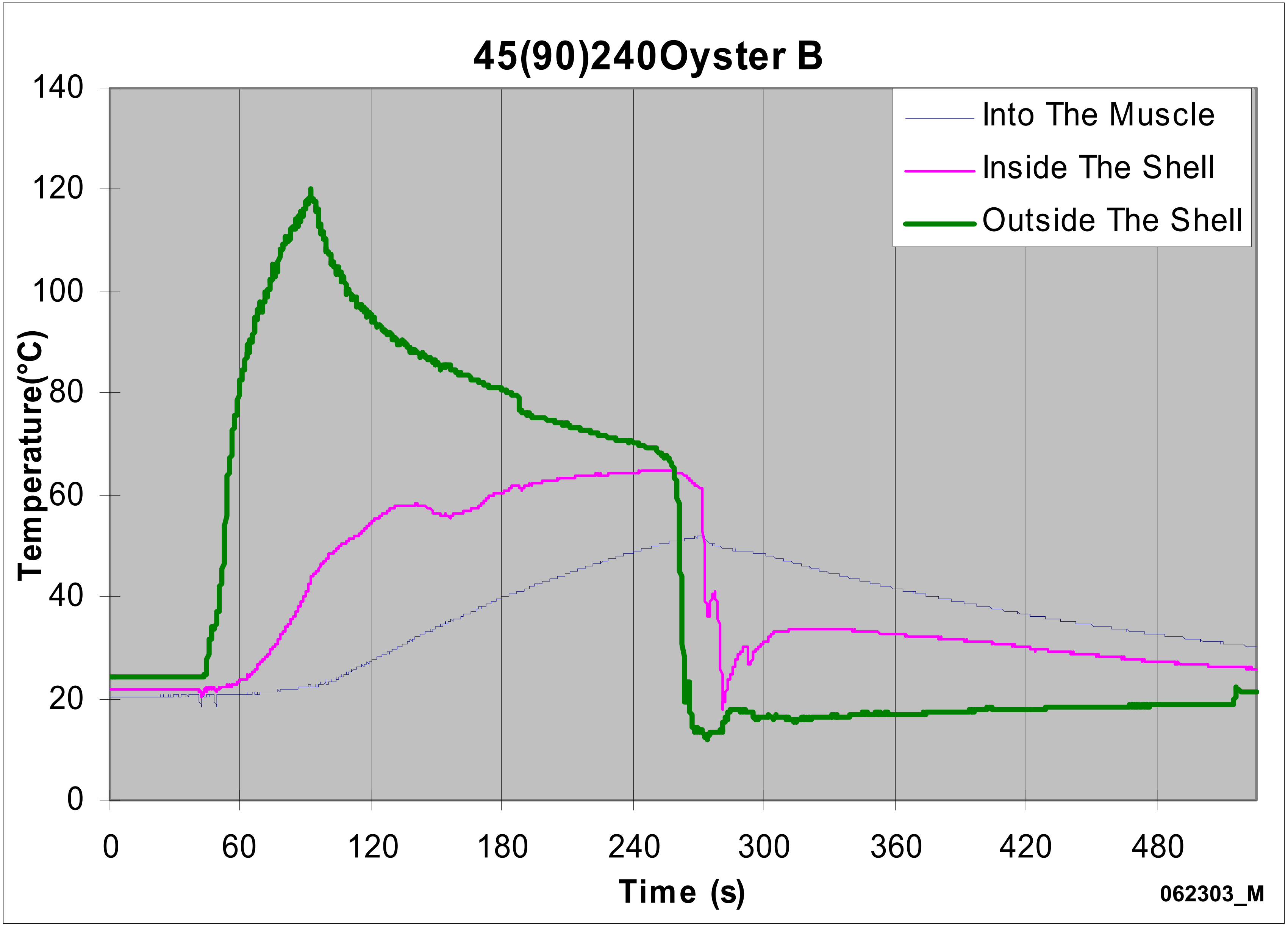
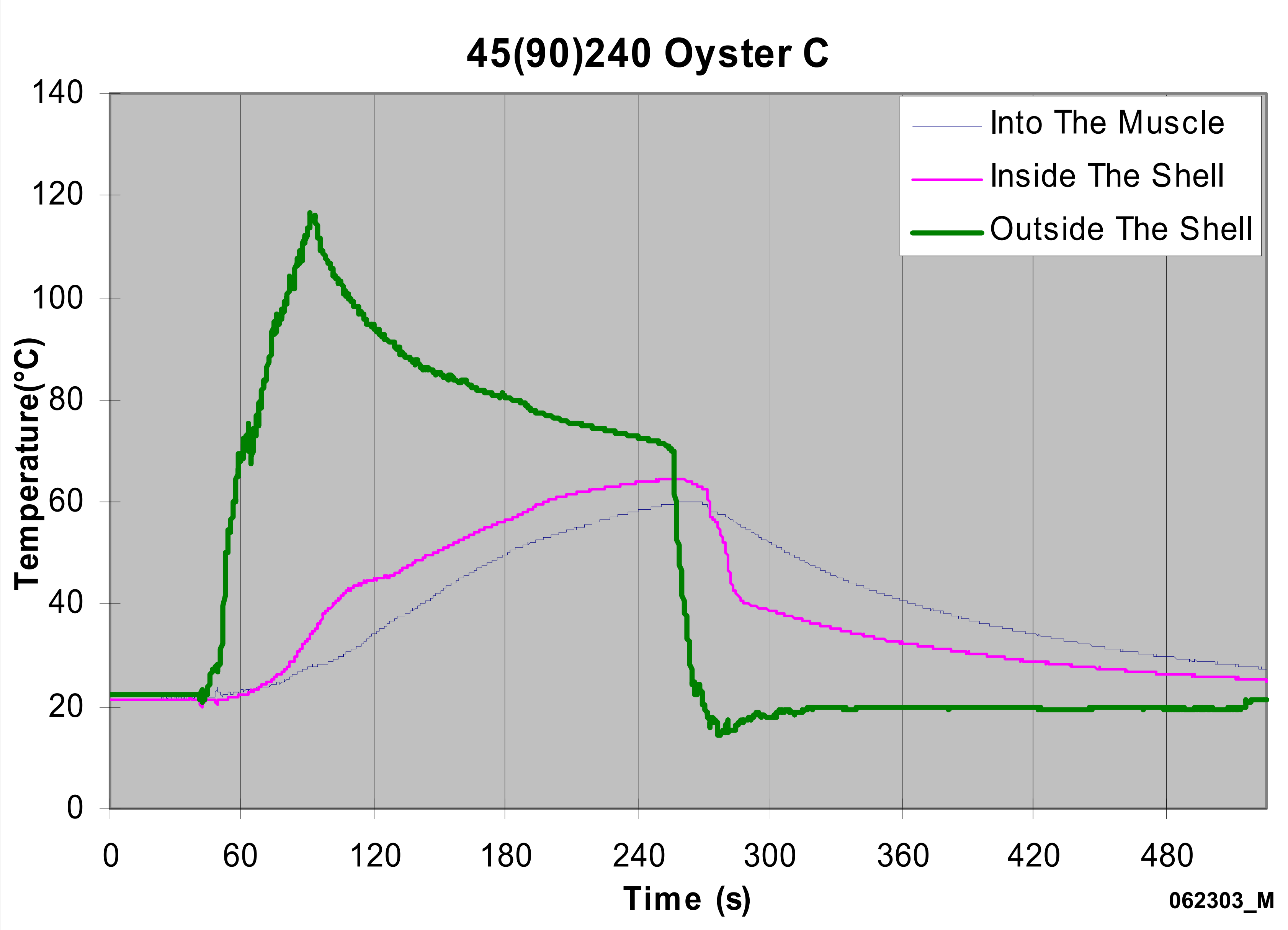
360
420
480
540
600
062303_A

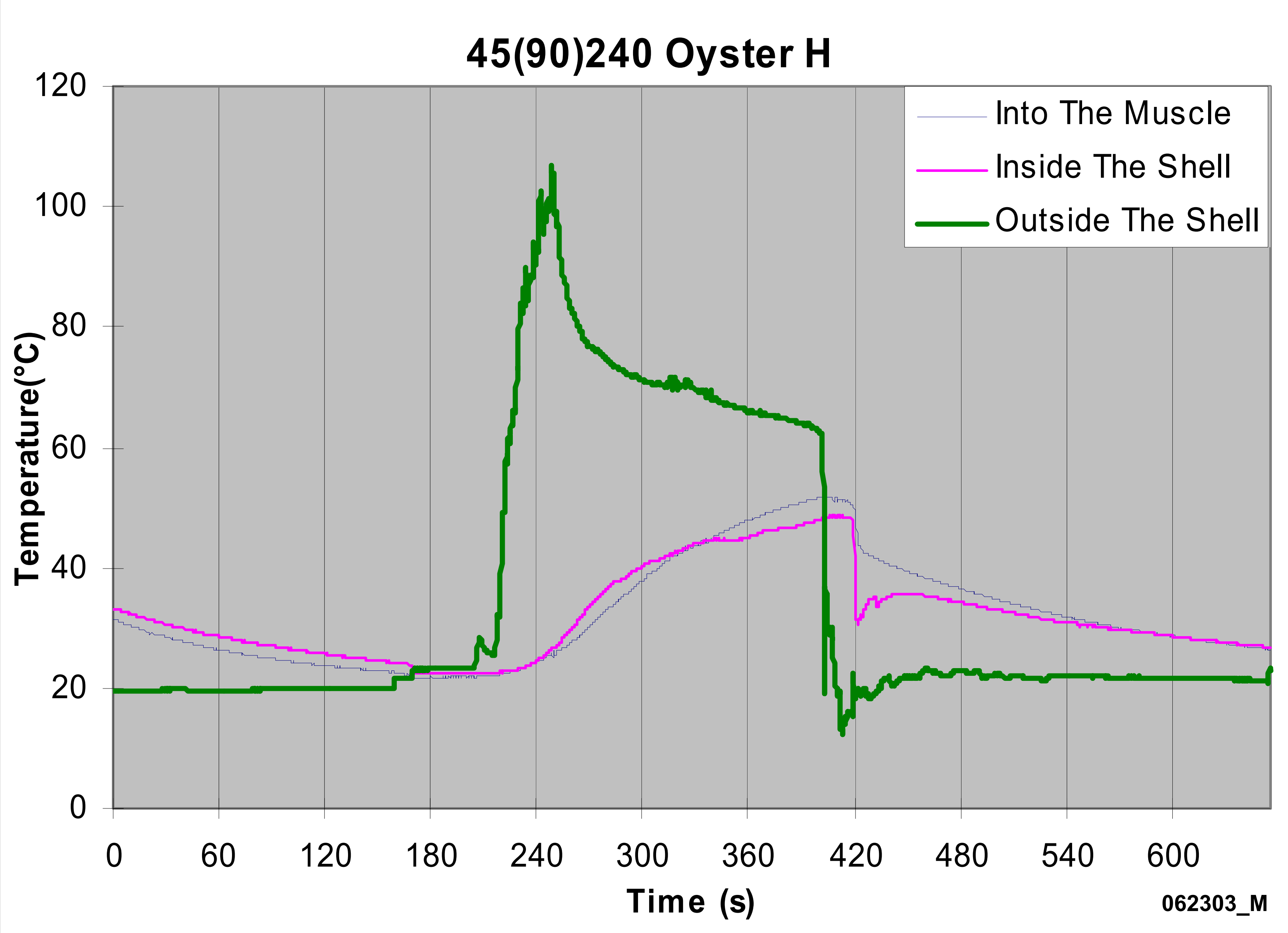

52(90)240 Oyster J
Into the Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
062303_A

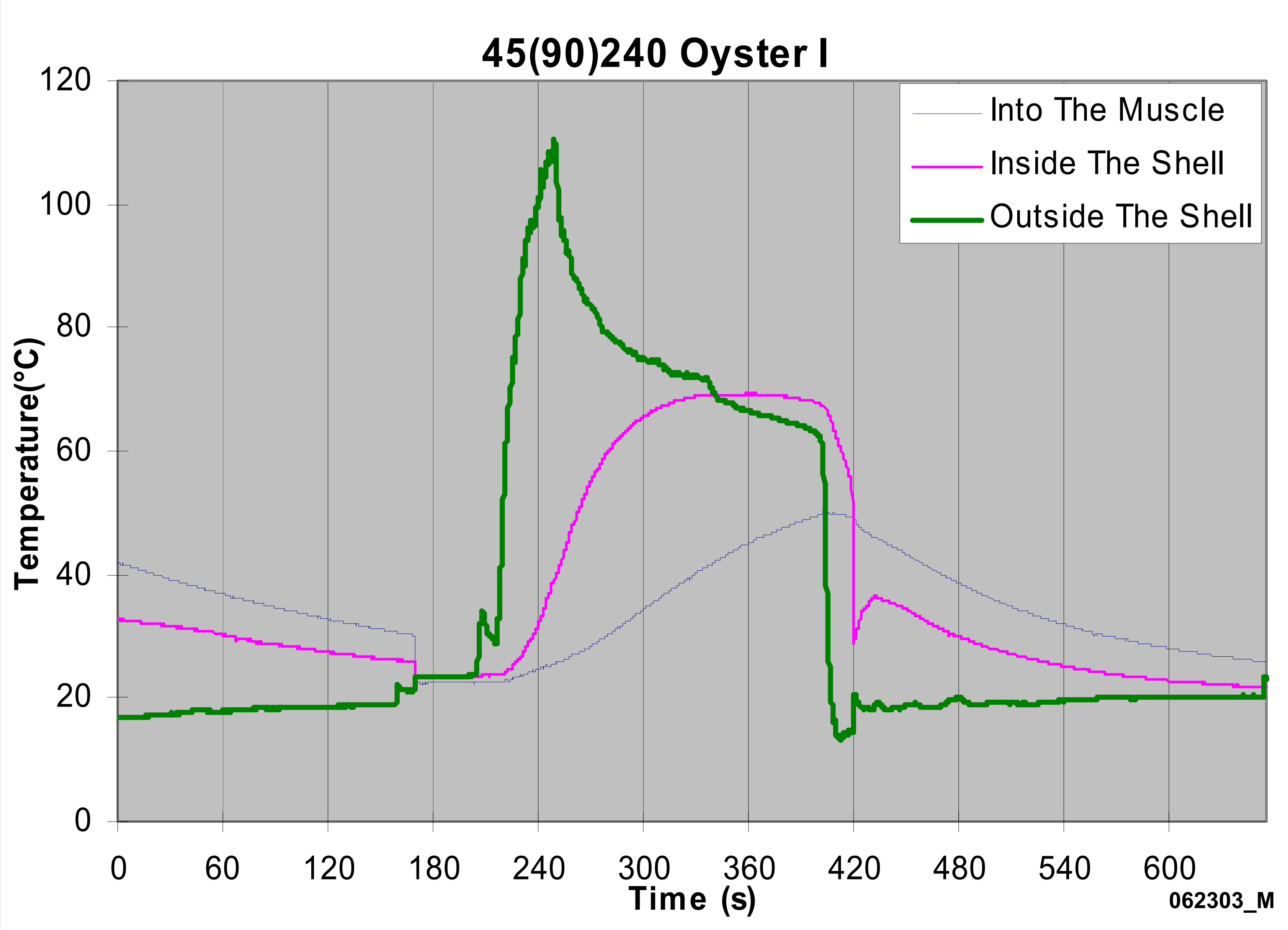

52(90)240 Oyster K
Temperature(°C)
0
20
40
60
80
100
120
140
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into the Muscle
Inside The Shell
Outside The Shell
062303_M

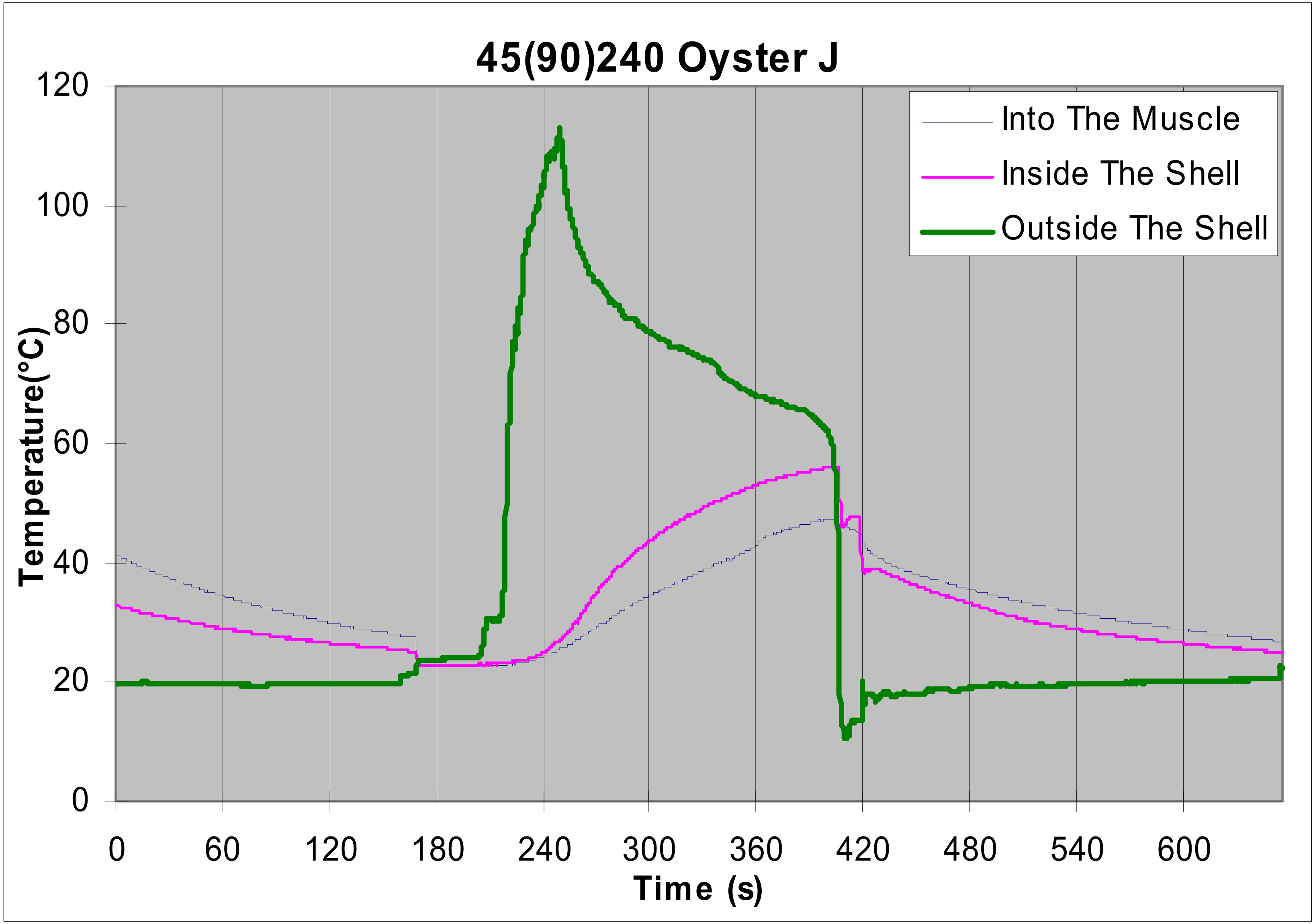

45(90)240 Oyster A
Temperature(°C)
0
20
40
60
80
100
120
0
60
120
180
240
300
360
420
480
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
062303_M


45(90)240Oyster B
Temperature(°C)
0
20
40
60
80
100
120
140
Time (s)
0
60
120
180
240
300
360
420
480
Into The Muscle
Inside The Shell
Outside The Shell
062303_M

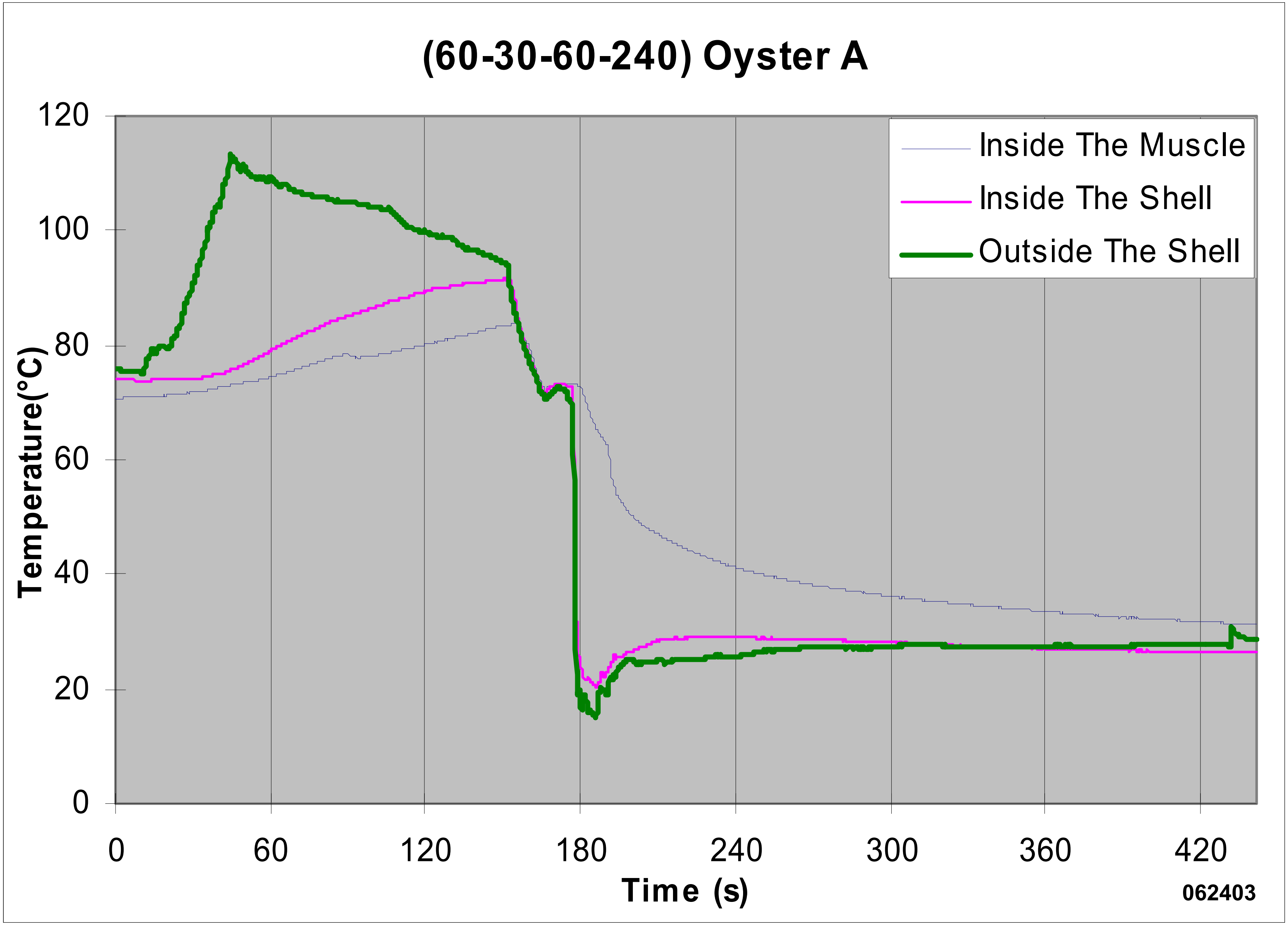

45(90)240 Oyster C
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
062303_M


45(90)240 Oyster H
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
062303_M

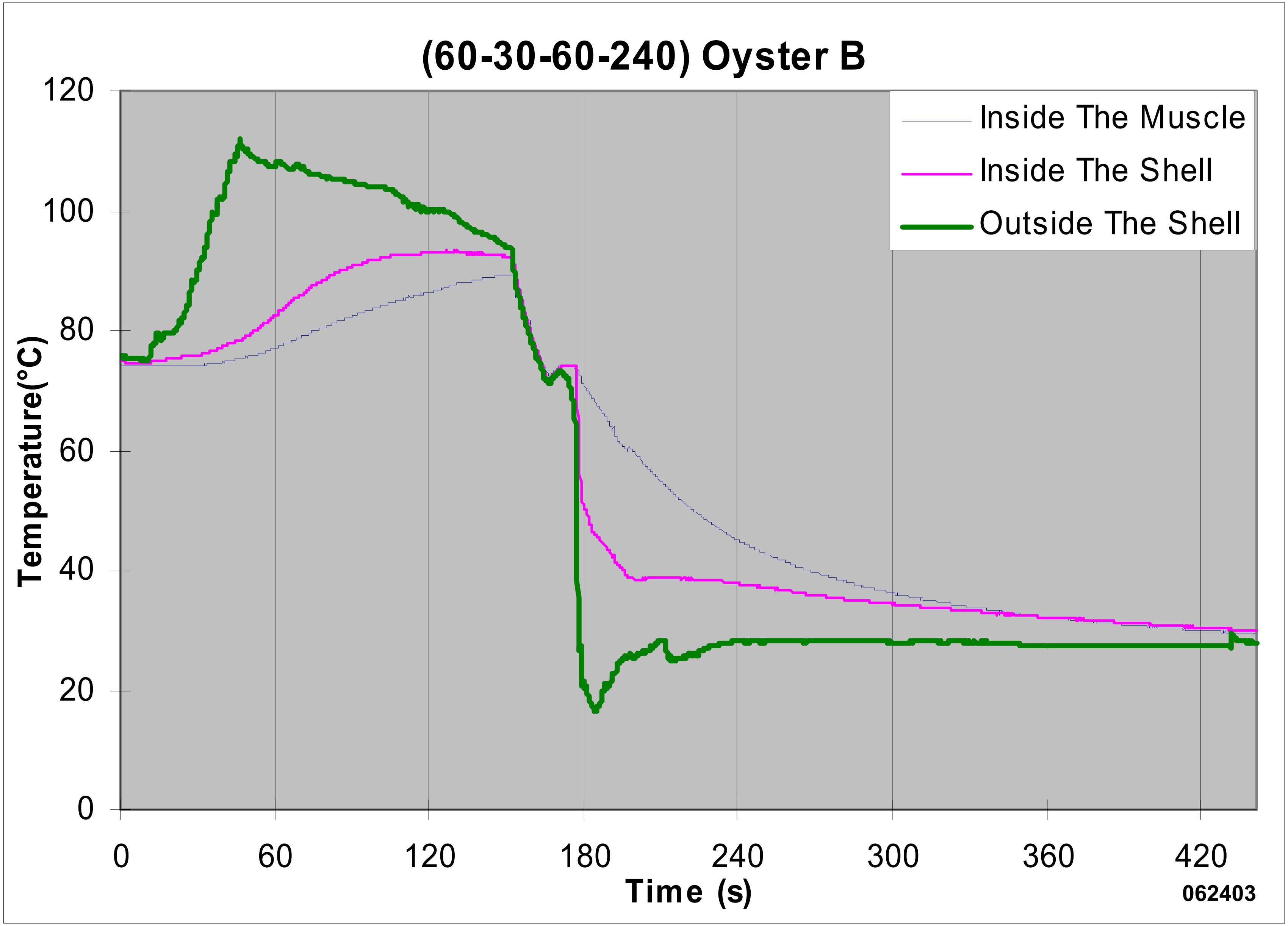

45(90)240 Oyster I
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
480
540
600
062303_M

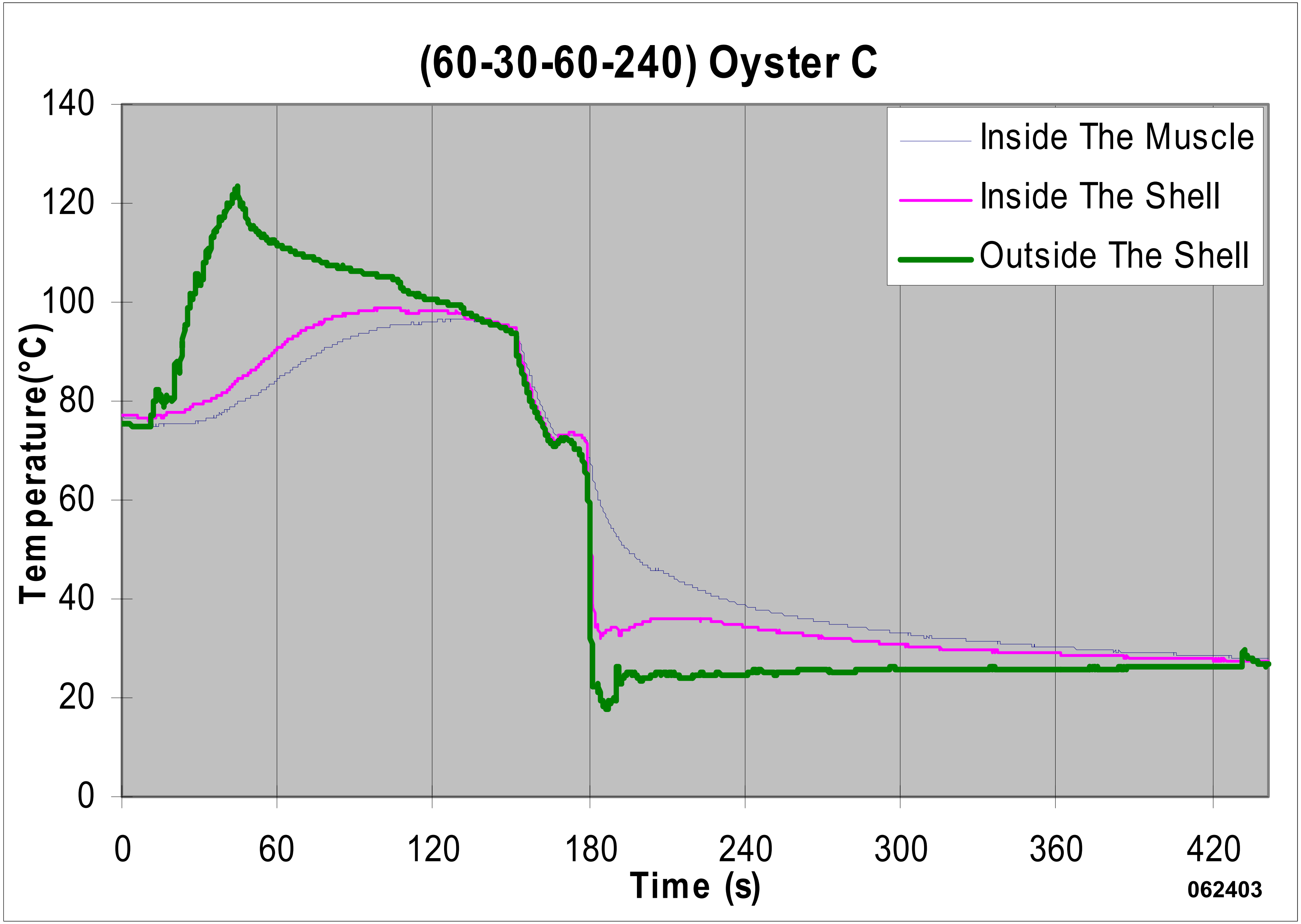

45(90)240 Oyster J
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)

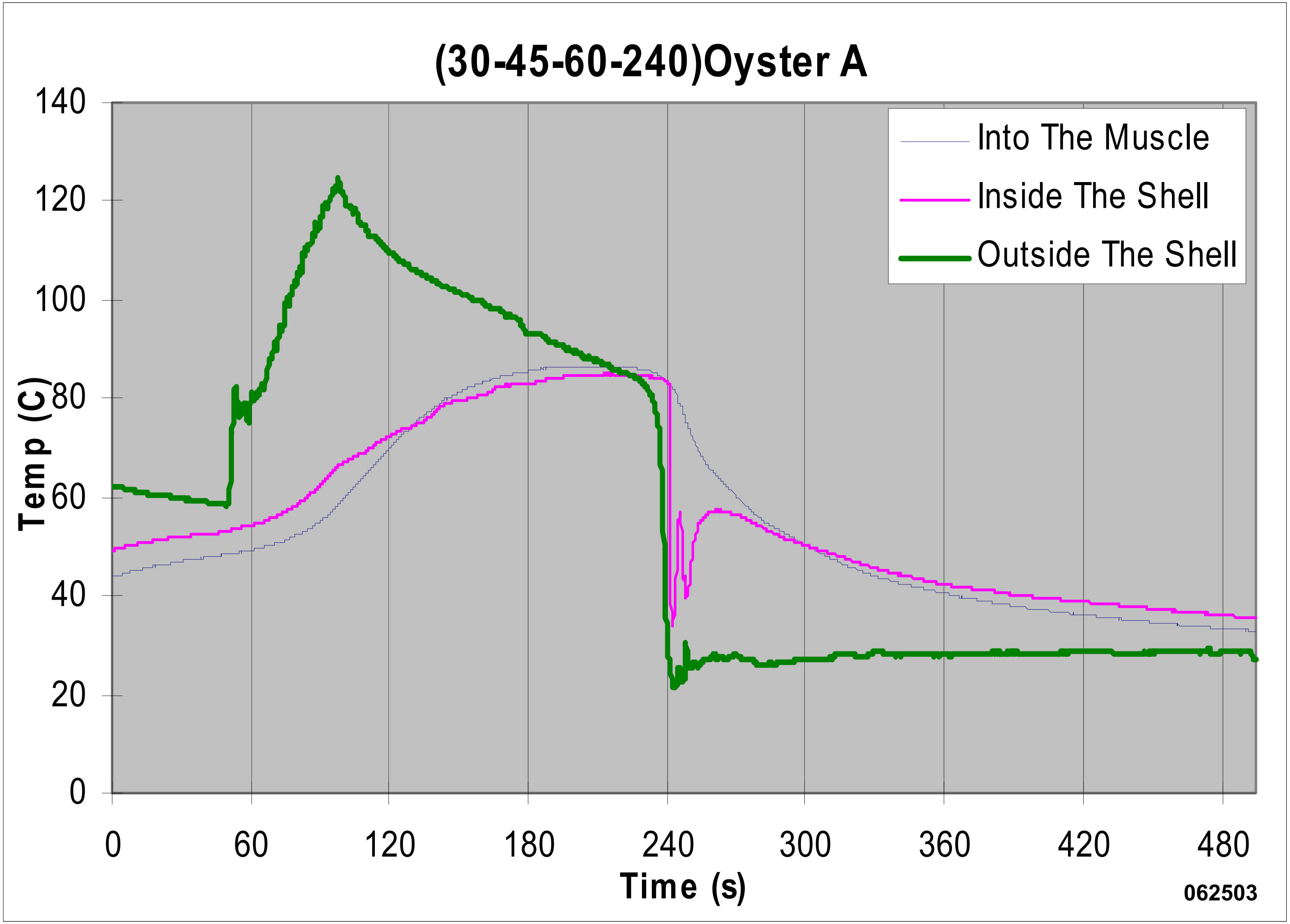
062303_M

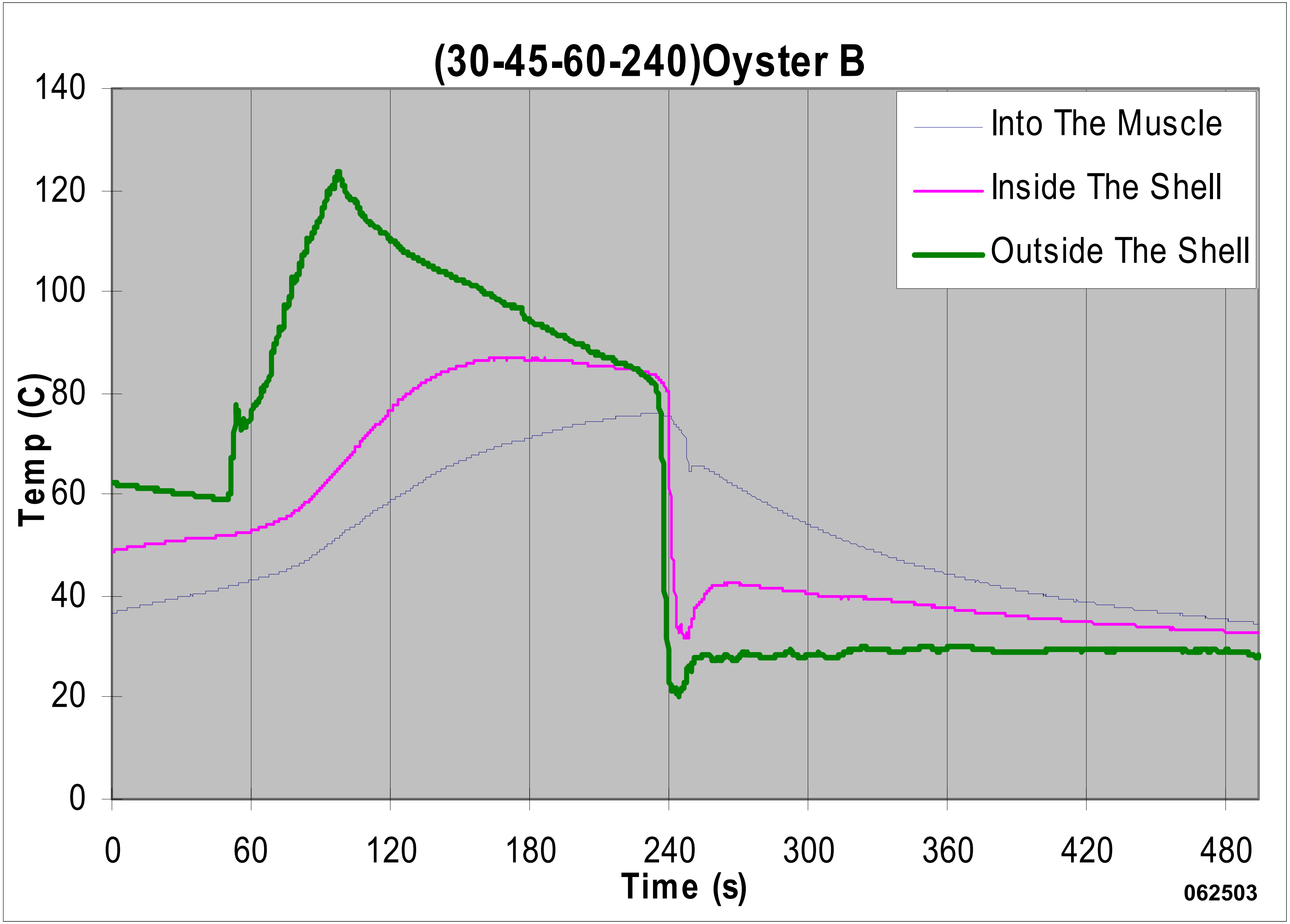


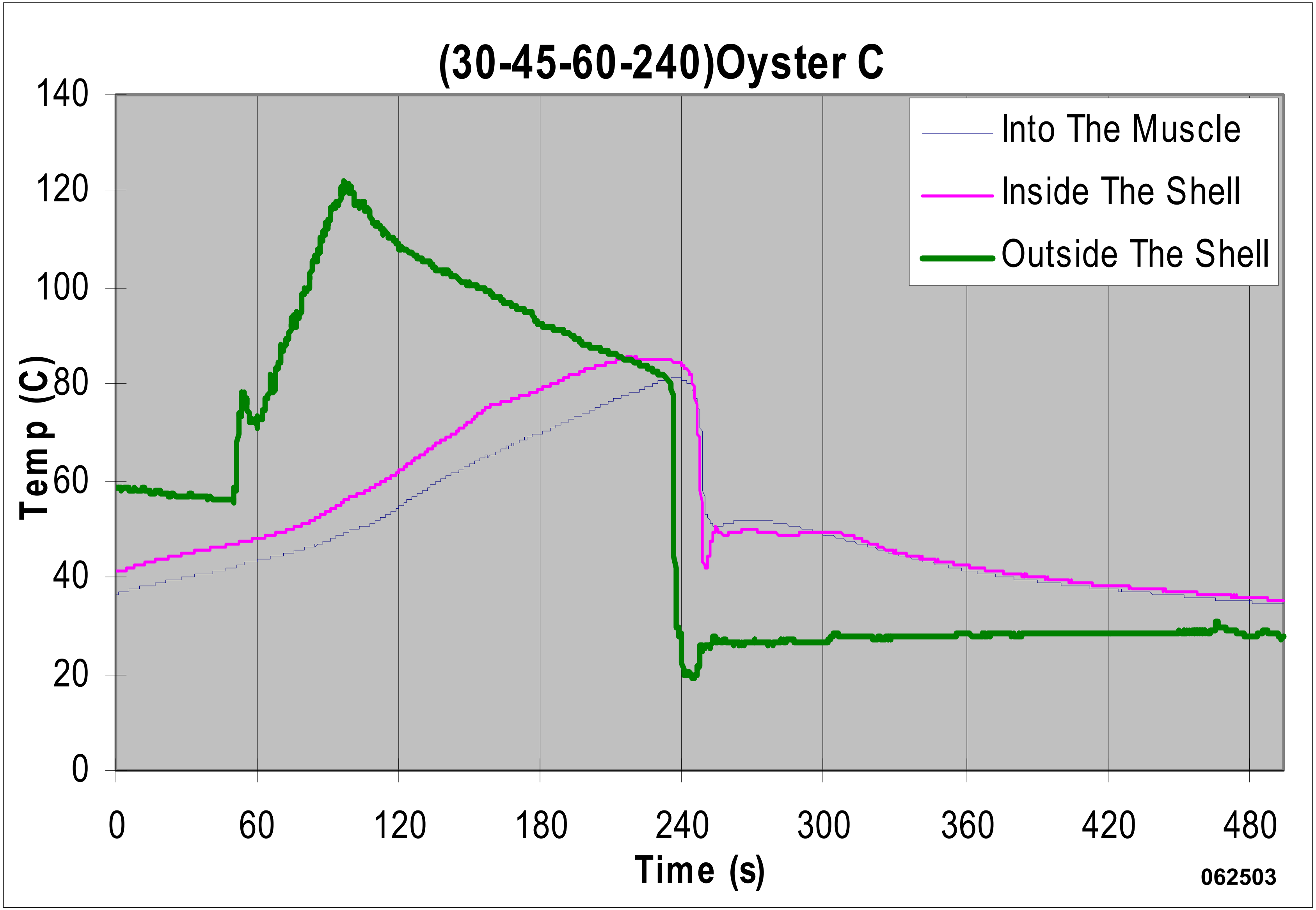
(60-30-60-240) Oyster A

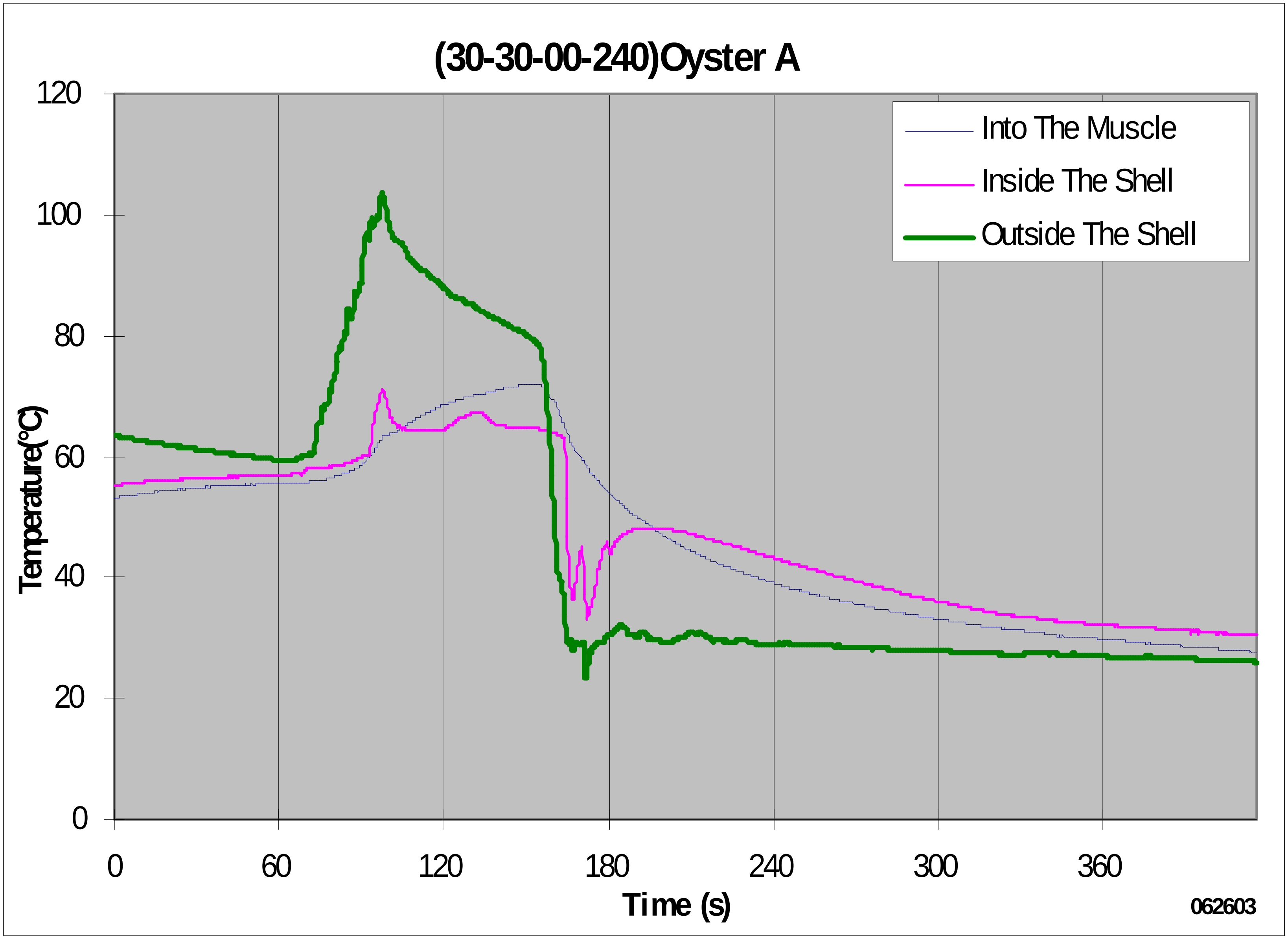

(60-30-60-240) Oyster B
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
Inside The Muscle
Inside The Shell
Outside The Shell
062403

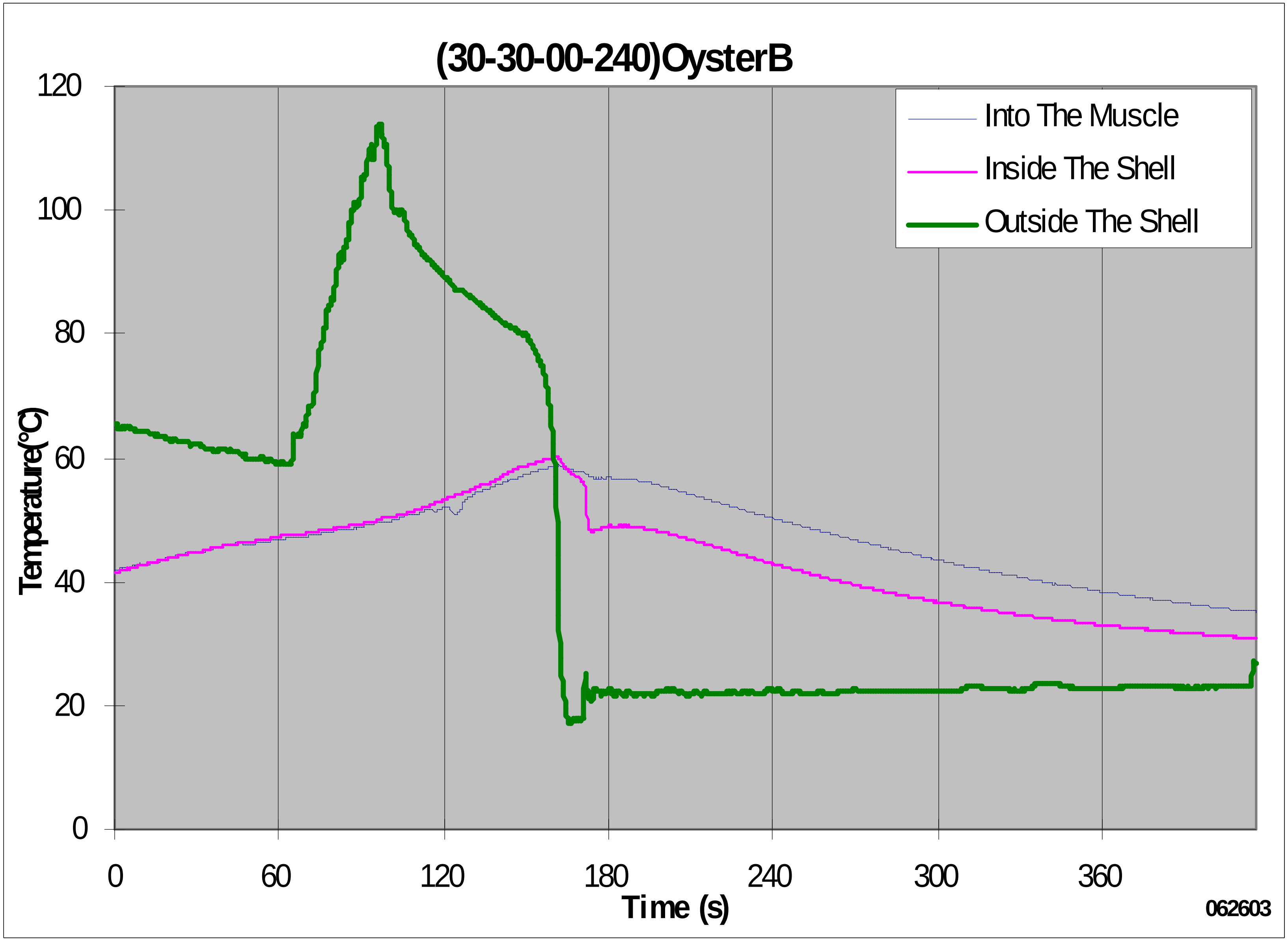

(60-30-60-240) Oyster C
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
Time (s)
Inside The Muscle
Inside The Shell
Outside The Shell
062403

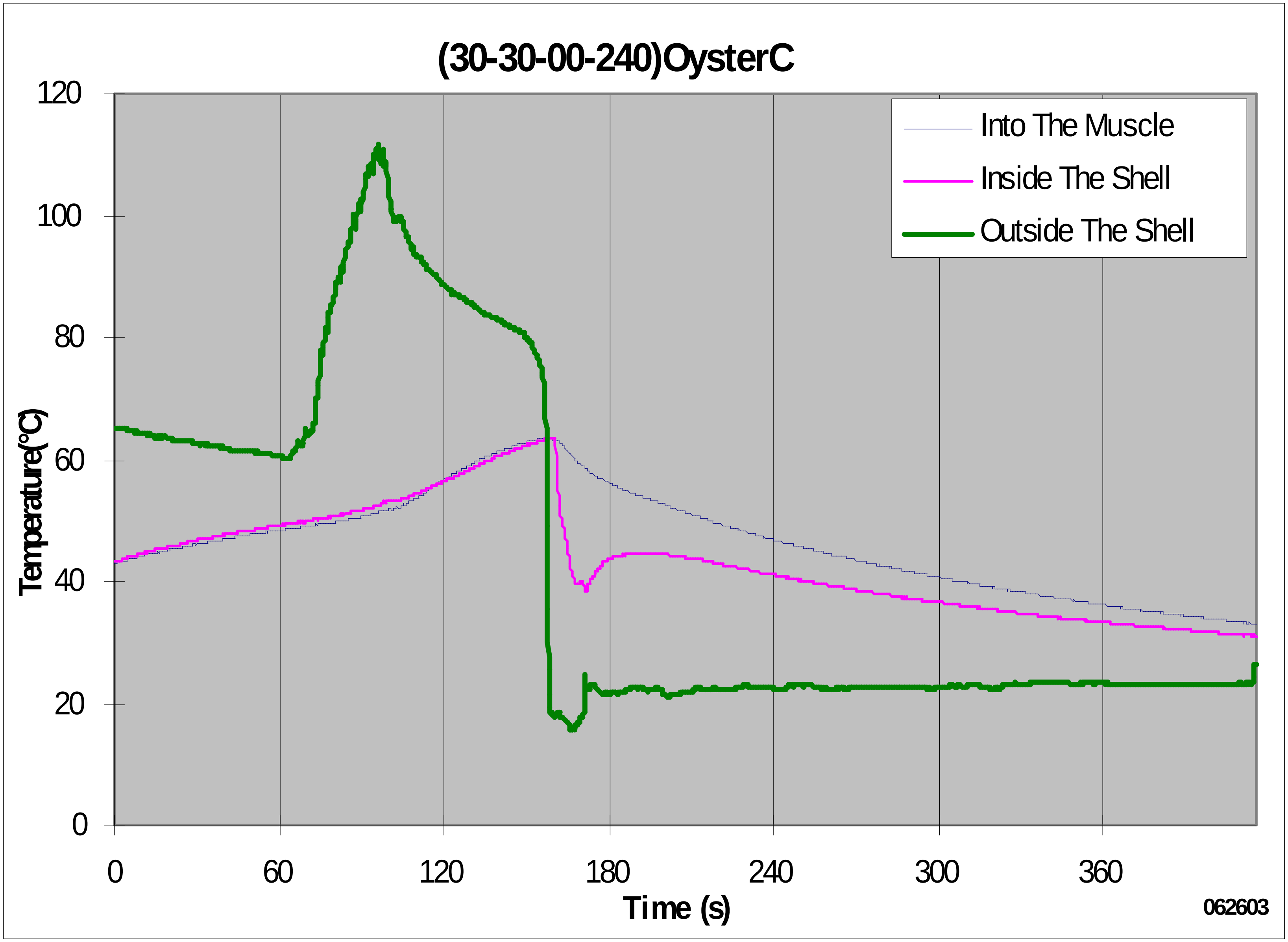

(30-45-60-240)Oyster A
Into The Muscle
Inside The Shell
Outside The Shell
Temp (C)
0
20
40
60
80
100
120
140
Time (s)
0
60
120
180
240
300
360
420
480
062503

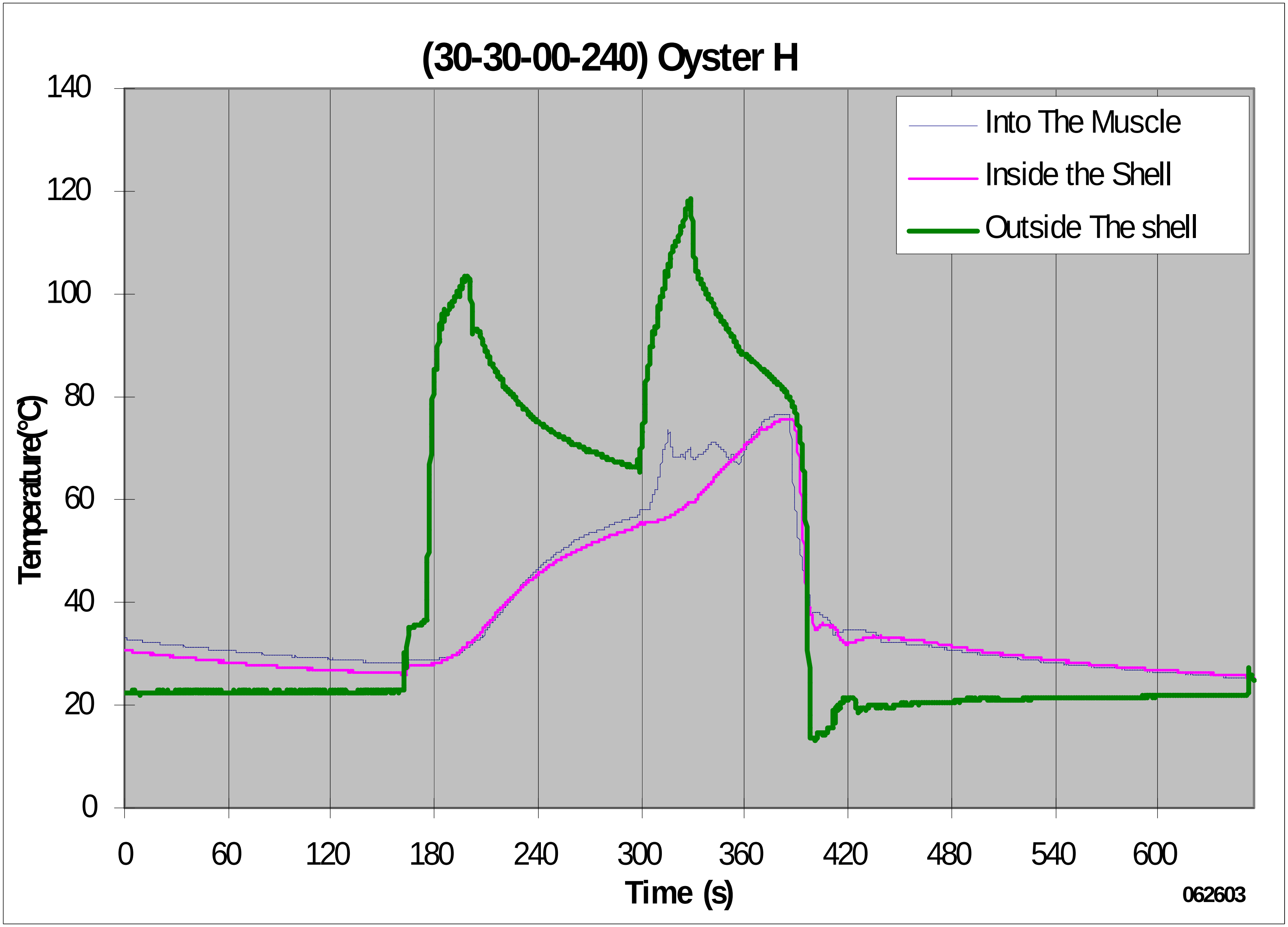

(30-45-60-240)Oyster B
Temp (C)
140
120
100
80
60
40
20
0
Time (s)
0
60
120
180
240
300
360
420
480
Into The Muscle
Inside The Shell
Outside The Shell
062503

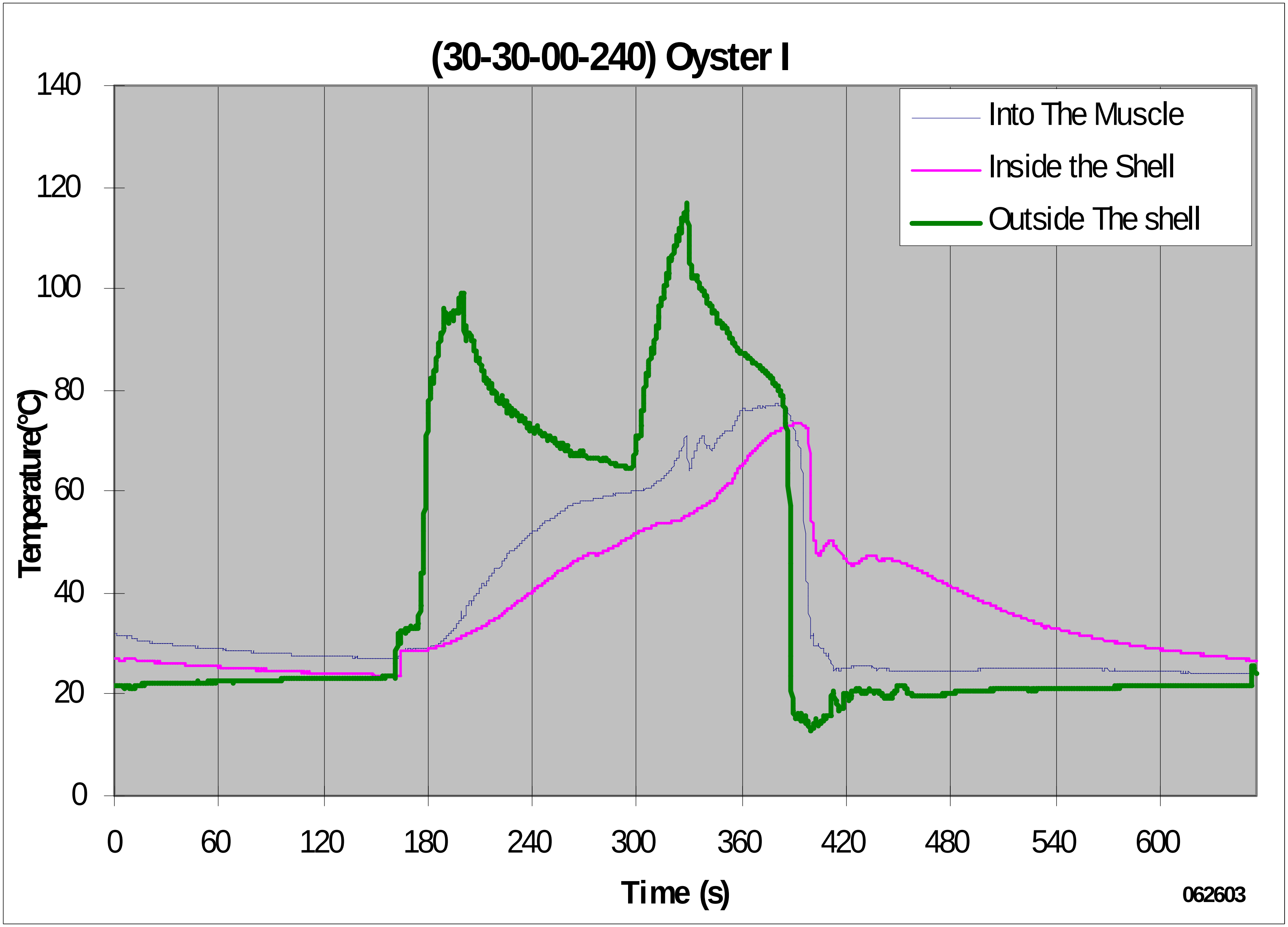

(30-45-60-240)Oyster C
Into The Muscle
Inside The Shell
Outside The Shell
Temp (C)
0
20
40
60
80
100
120
140
0
60
120
180
240
300
360
420
480
Time (s)
062503

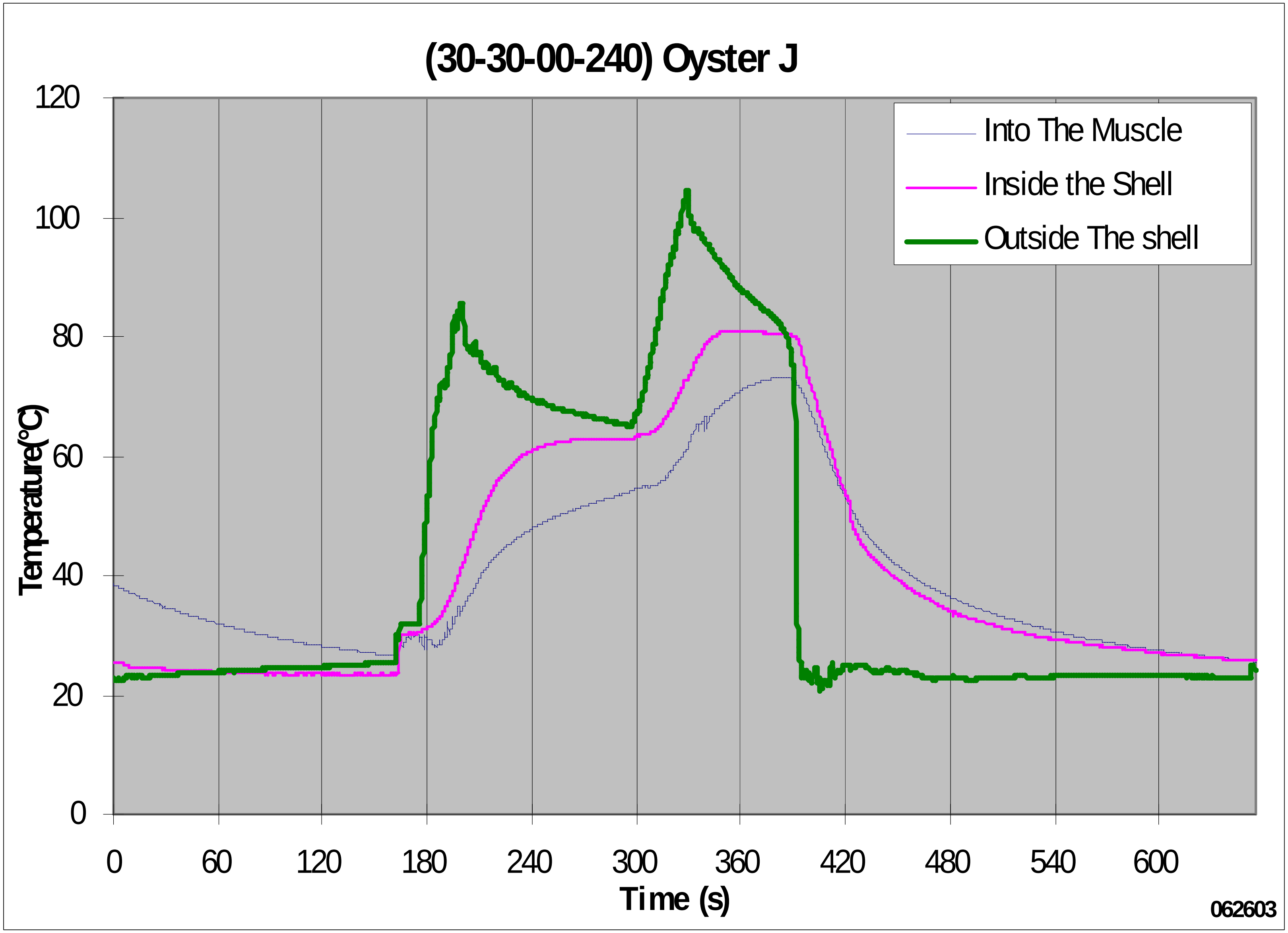

(30-30-00-240)Oyster A
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
Time (s)
062603

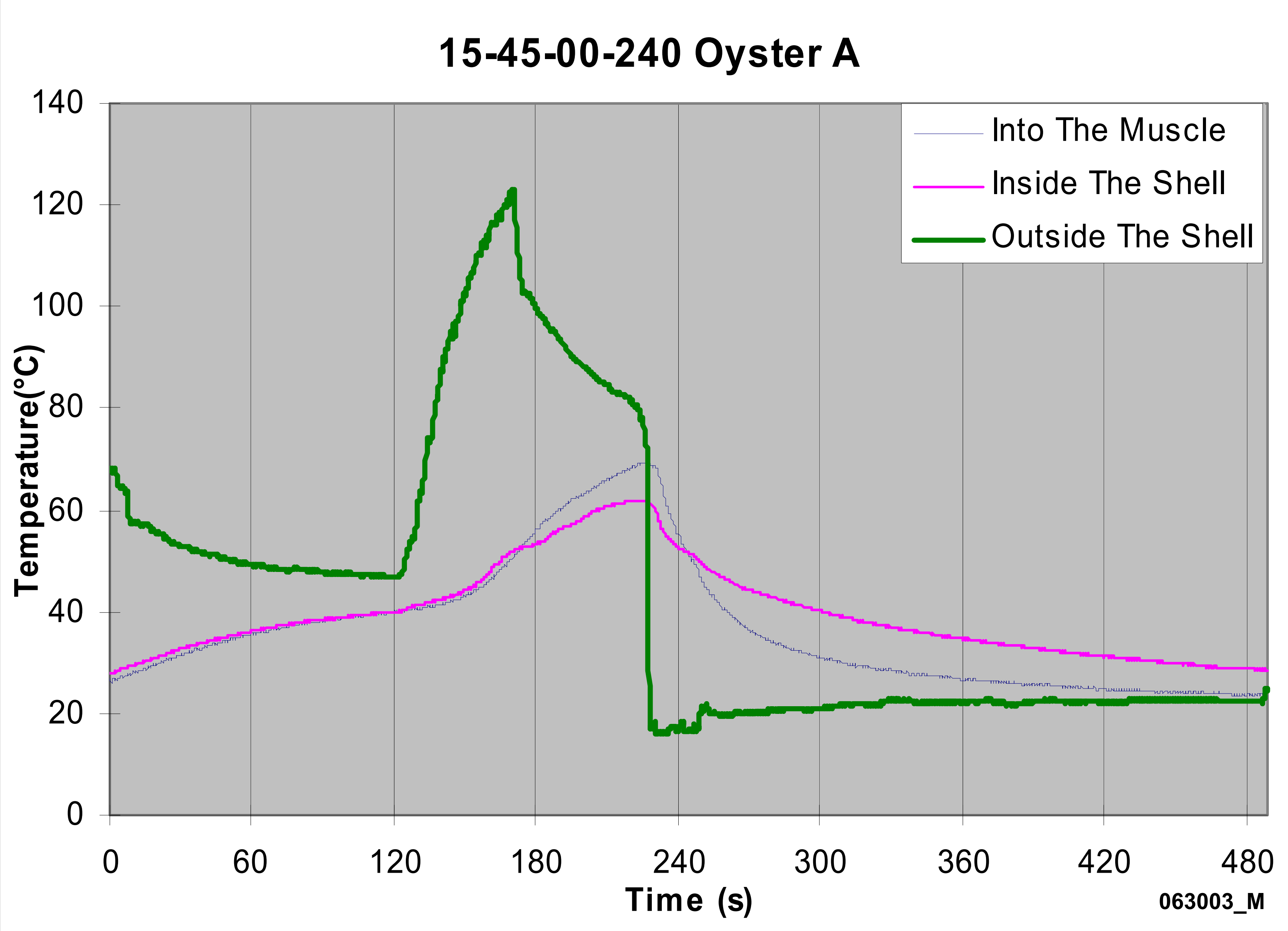

(30-30-00-240)OysterB
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
062603


(30-30-00-240)OysterC
120
100
80
60
40
20
0
Temperature(°C)
0
60
120
180
240
300
360
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
062603

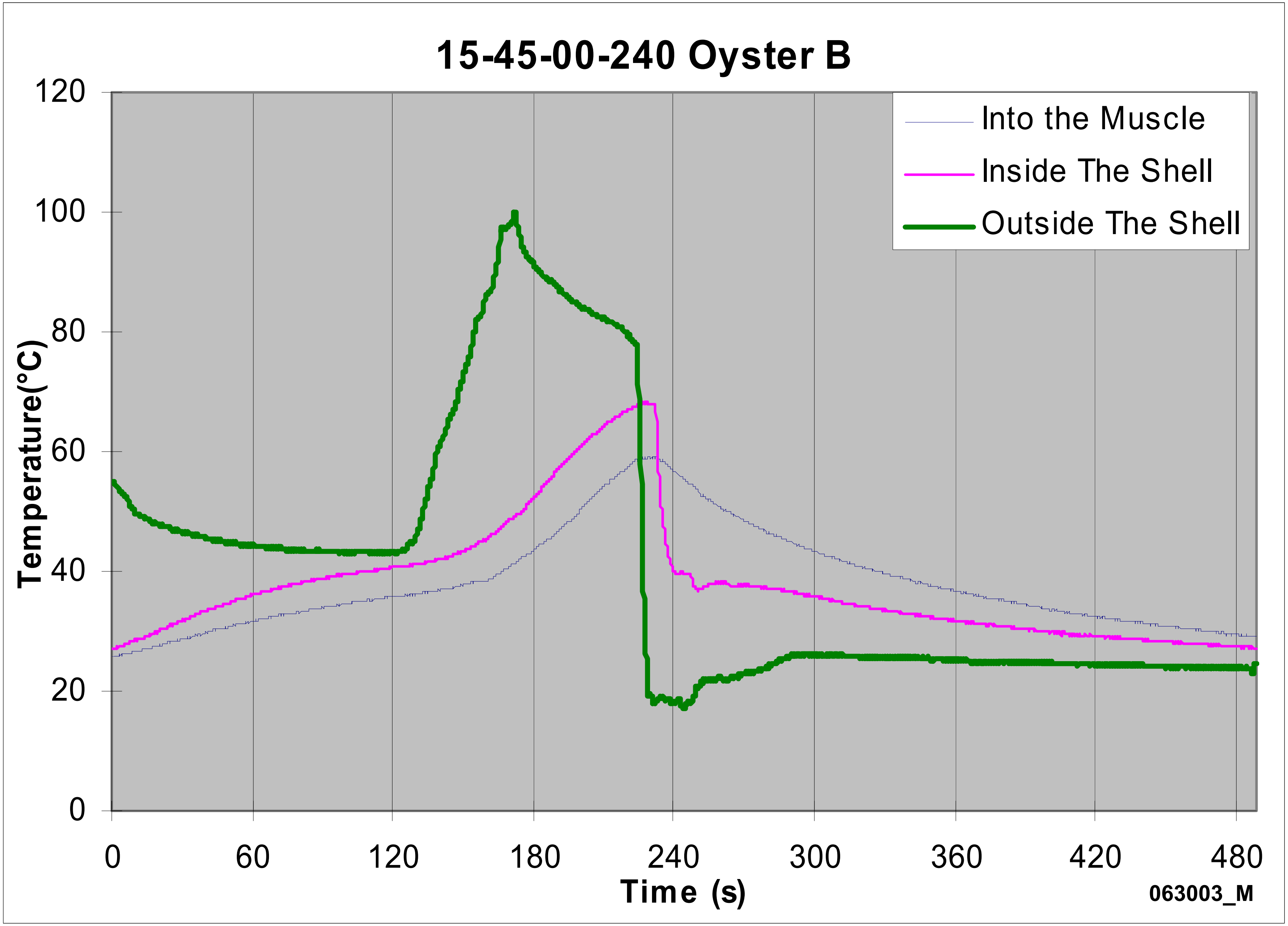

(30-30-00-240) Oyster H
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside the Shell
Outside The shell
062603


(30-30-00-240) Oyster I
140
120
100
80
60
40
20
0
Temperature(°C)
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Inside the Shell
Outside The shell
062603

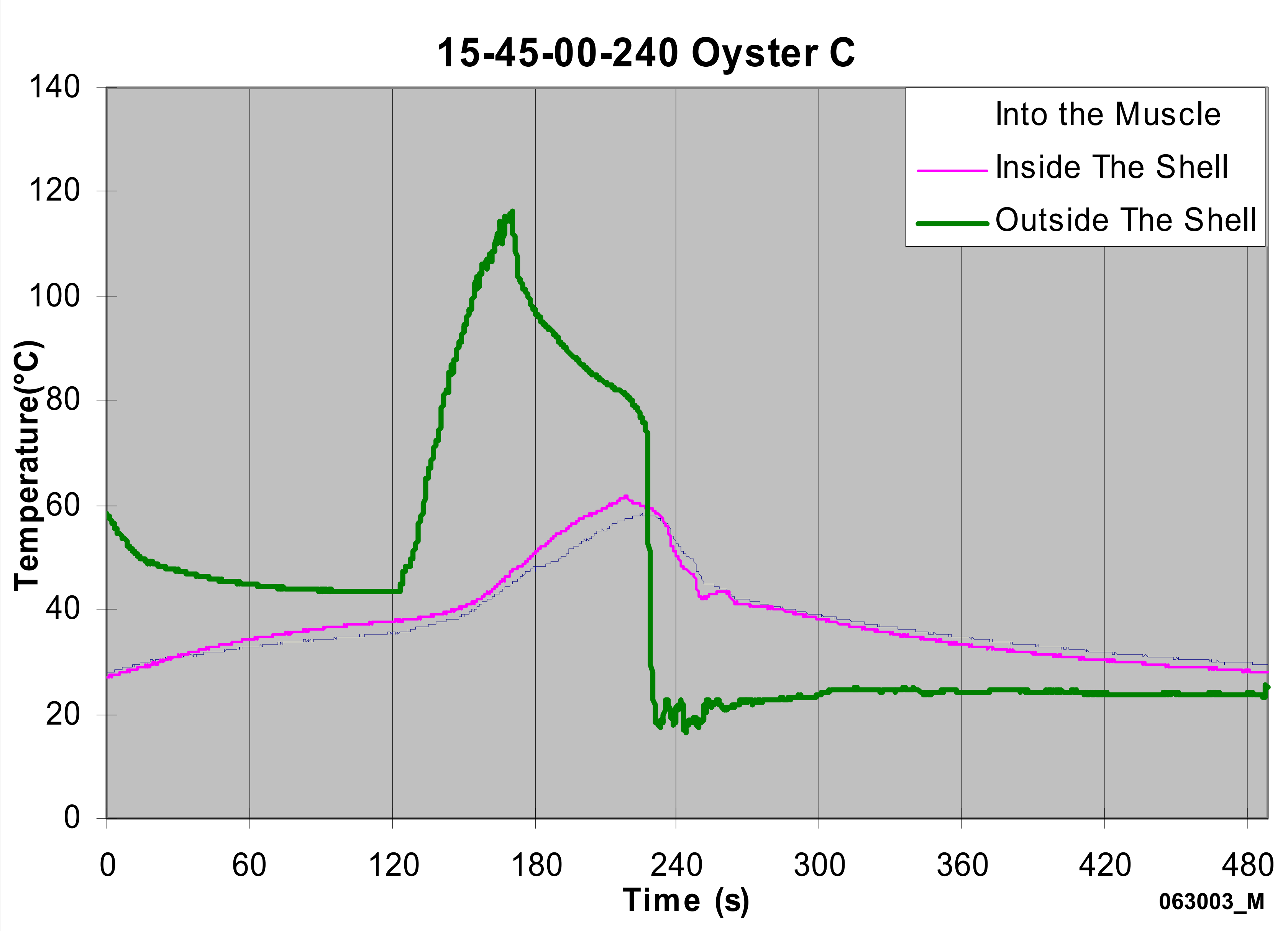

(30-30-00-240) Oyster J
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
480
540
600
Into The Muscle
Inside the Shell
Outside The shell
062603

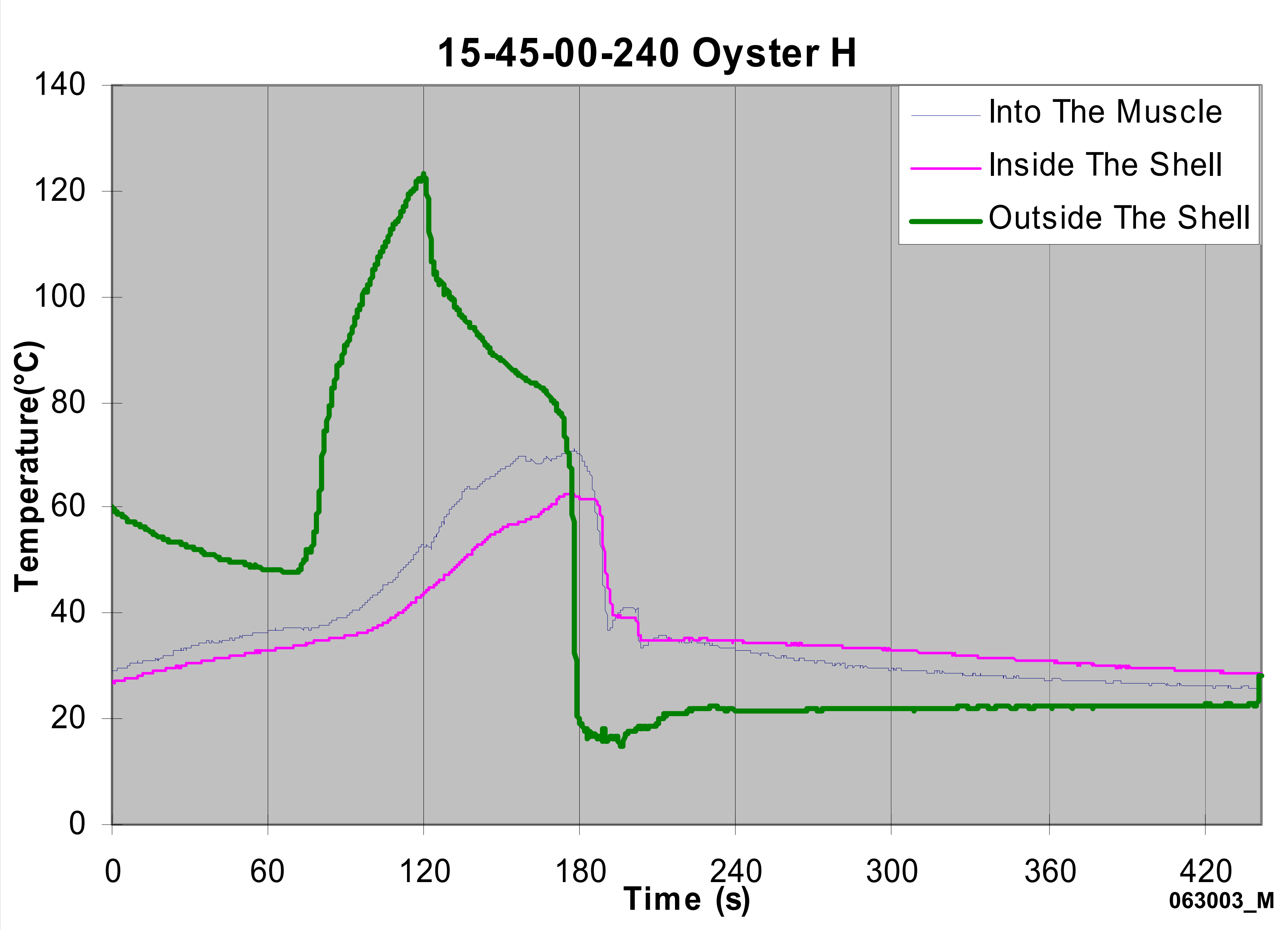


15-45-00-240 Oyster A

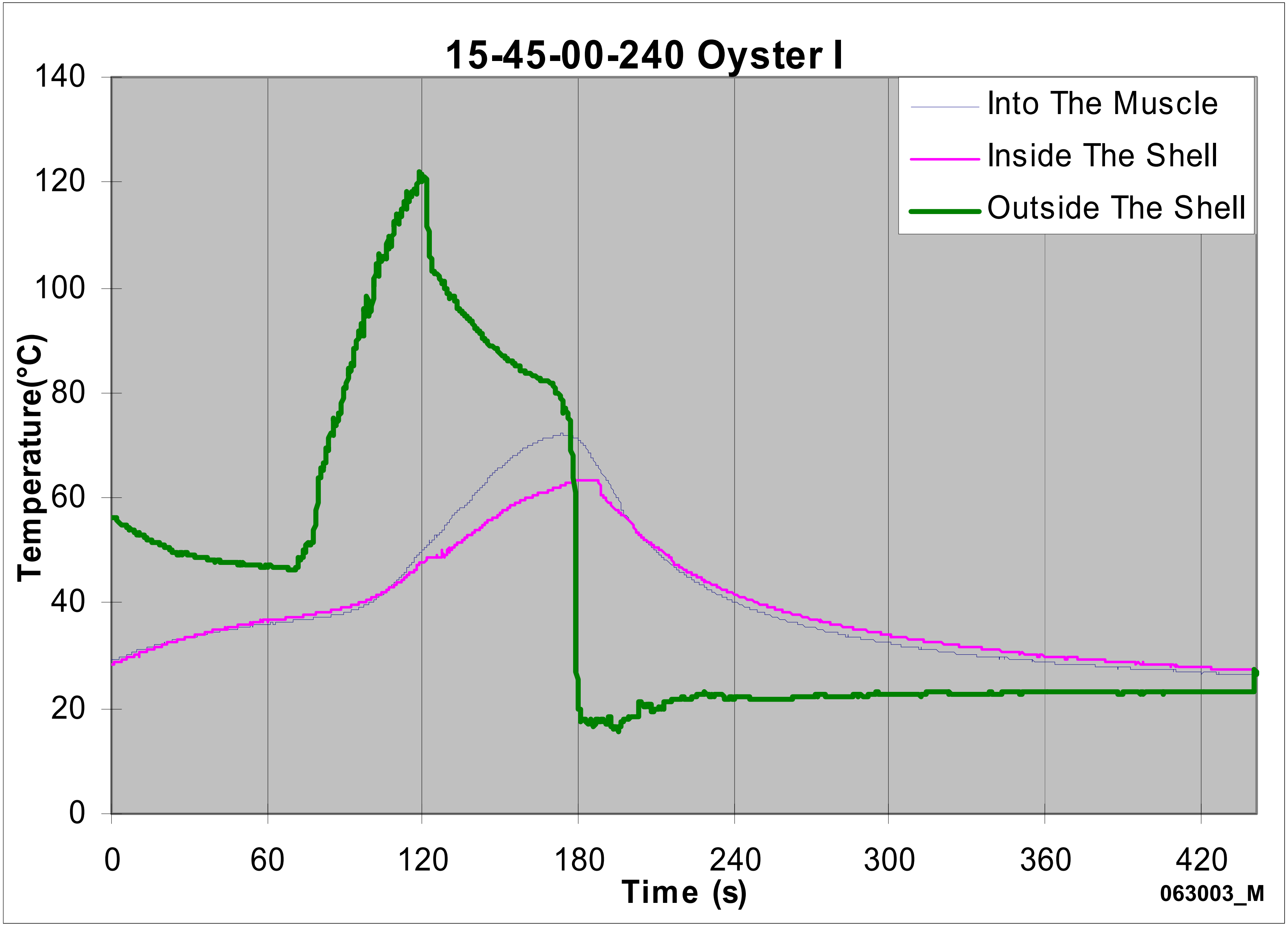


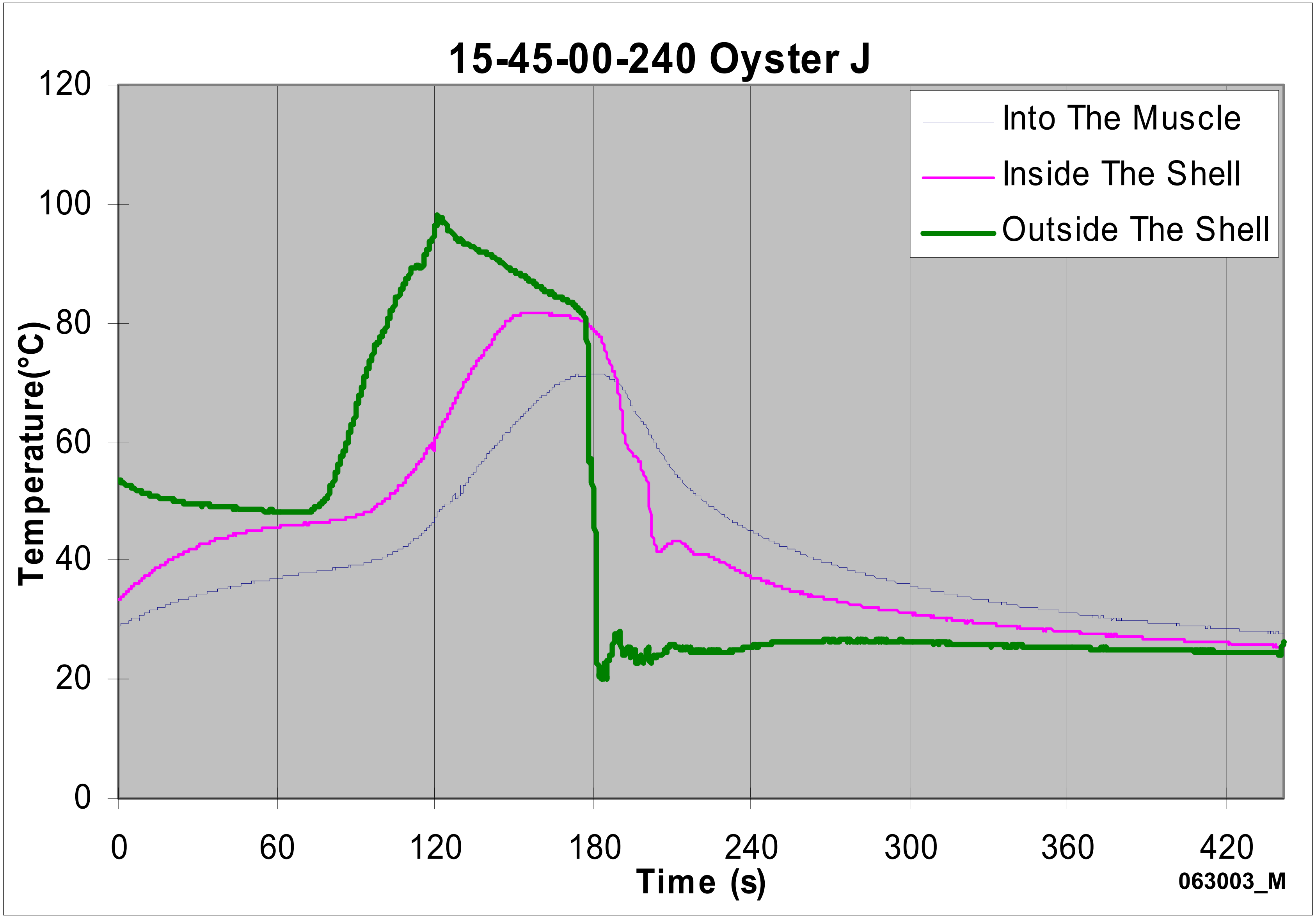
15-45-00-240 Oyster B

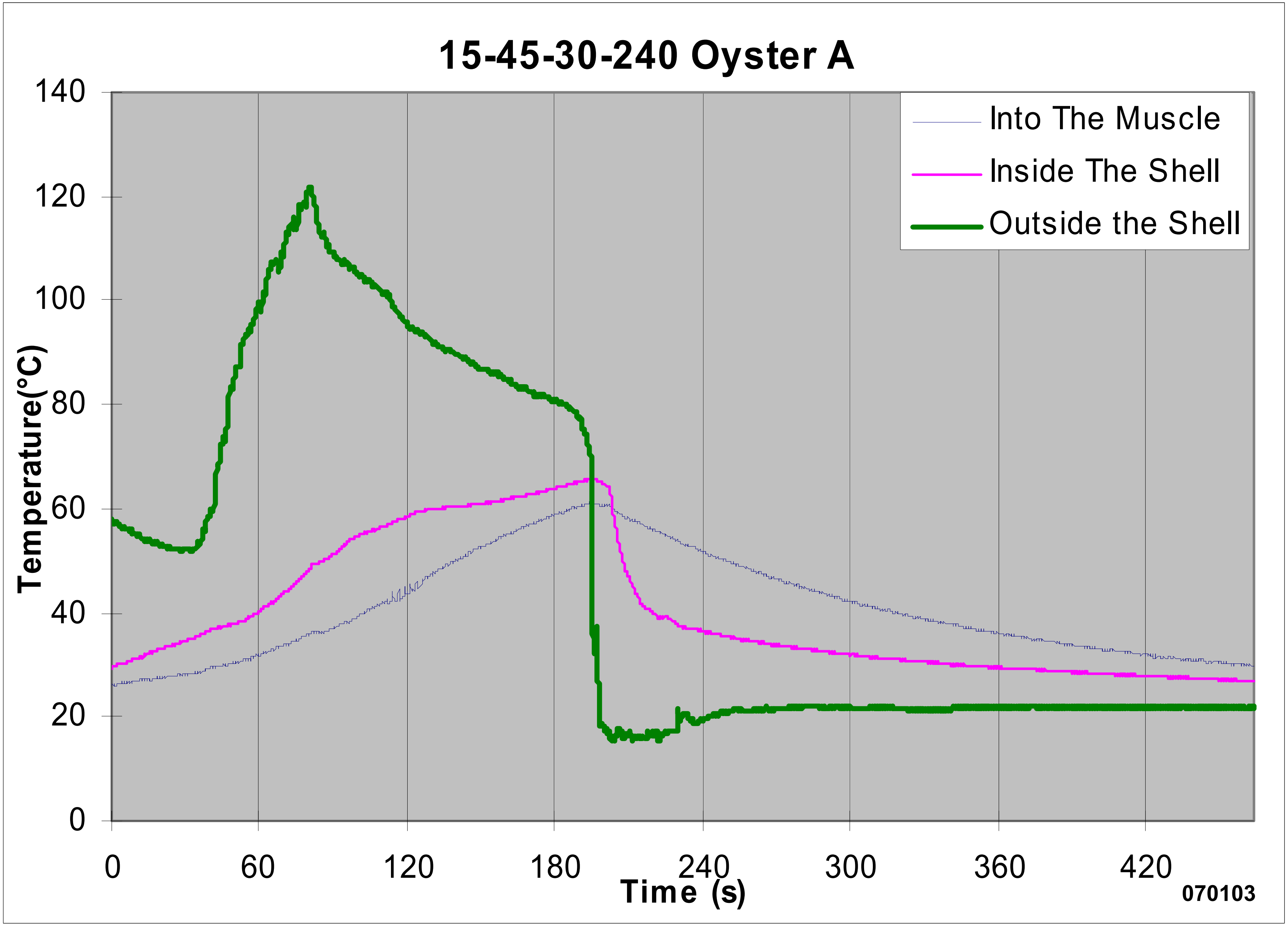

15-45-00-240 Oyster C
Into the Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
140
Time (s)
0
60
120
180
240
300
360
420
480
063003_M

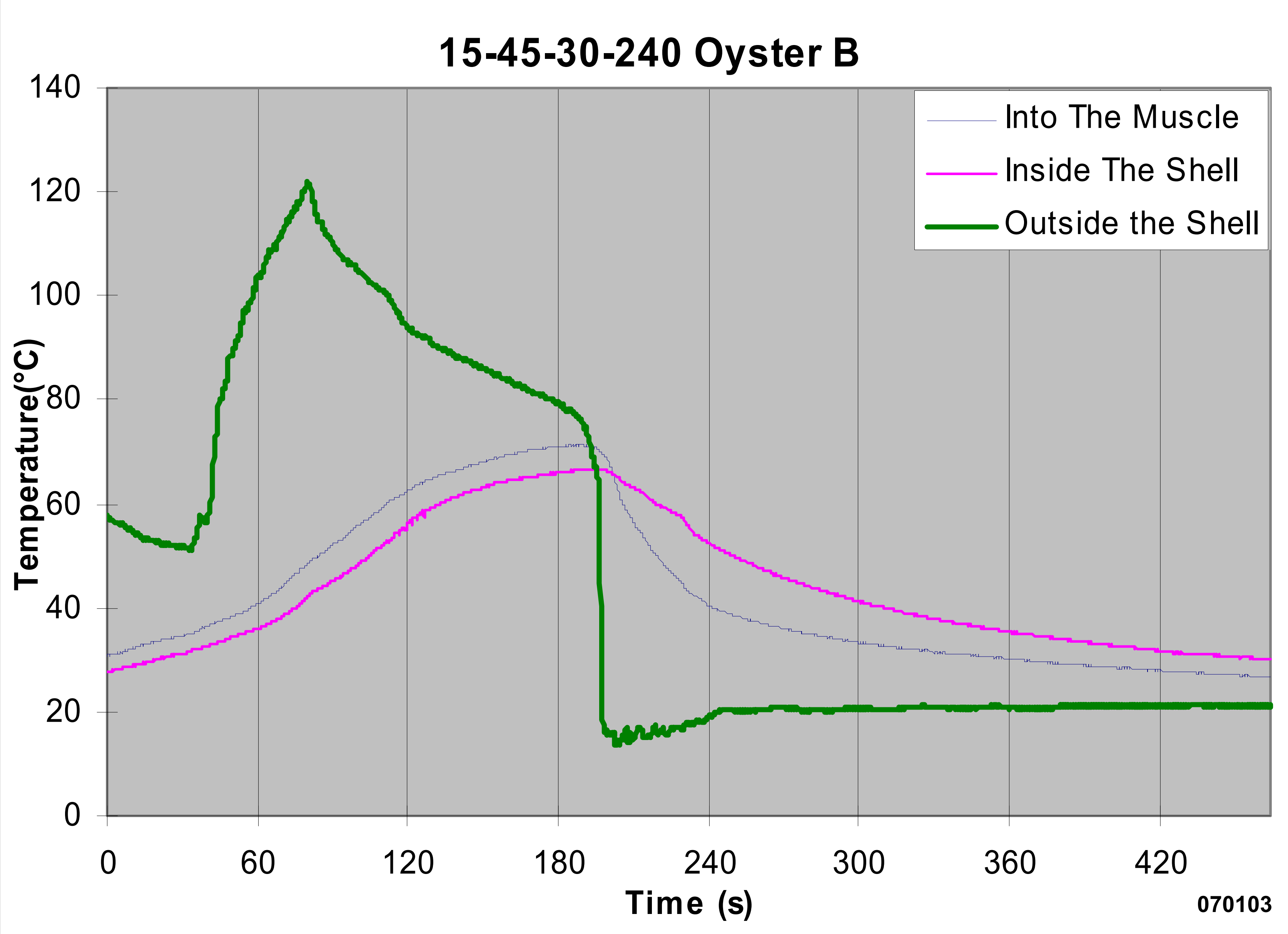


15-45-00-240 Oyster H

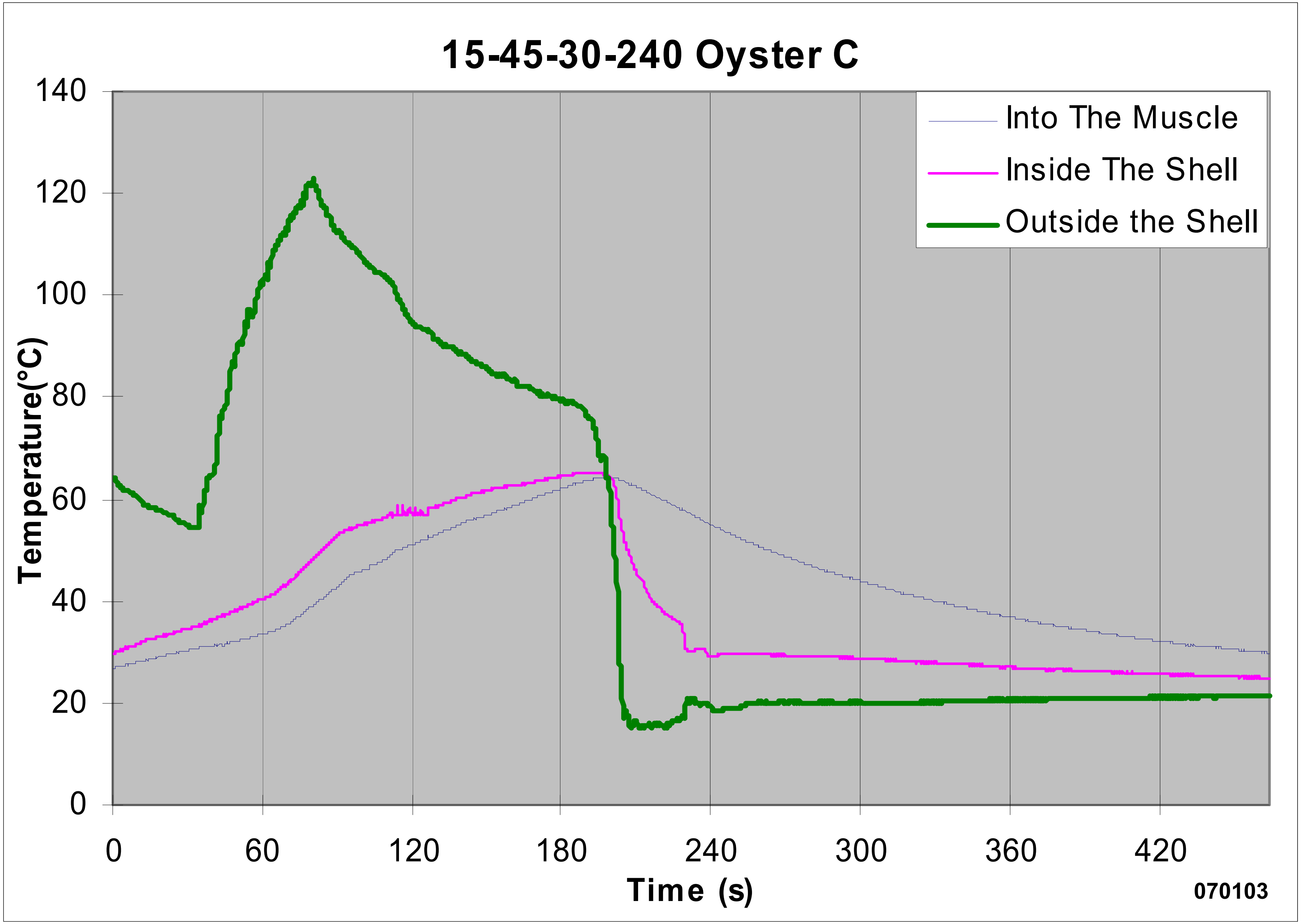

15-45-00-240 Oyster I
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
140
0
60
120
180
240
300
360
420
Time (s)
063003_M

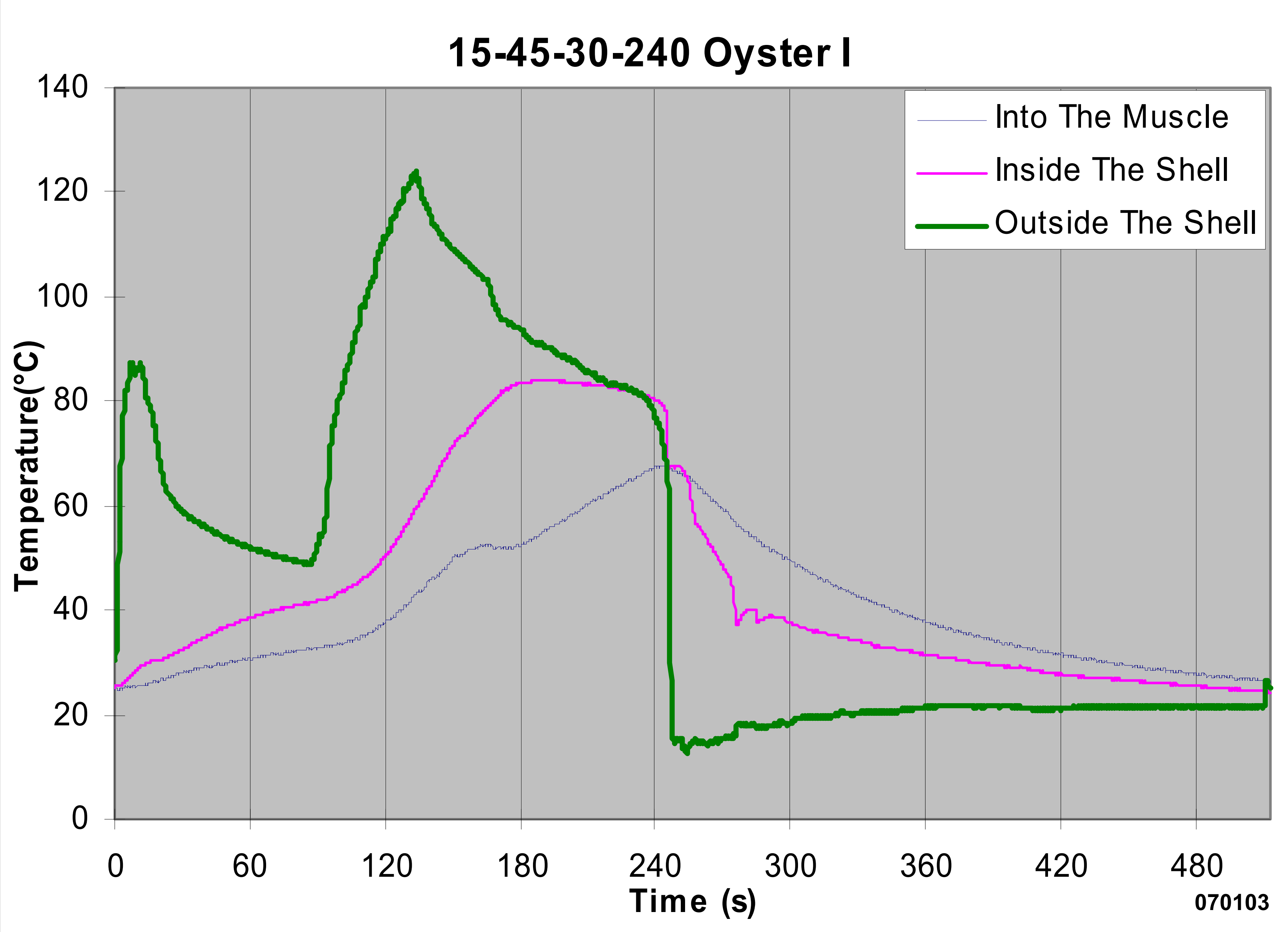

15-45-00-240 Oyster J
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
Into The Muscle
Inside The Shell
Outside The Shell
063003_M

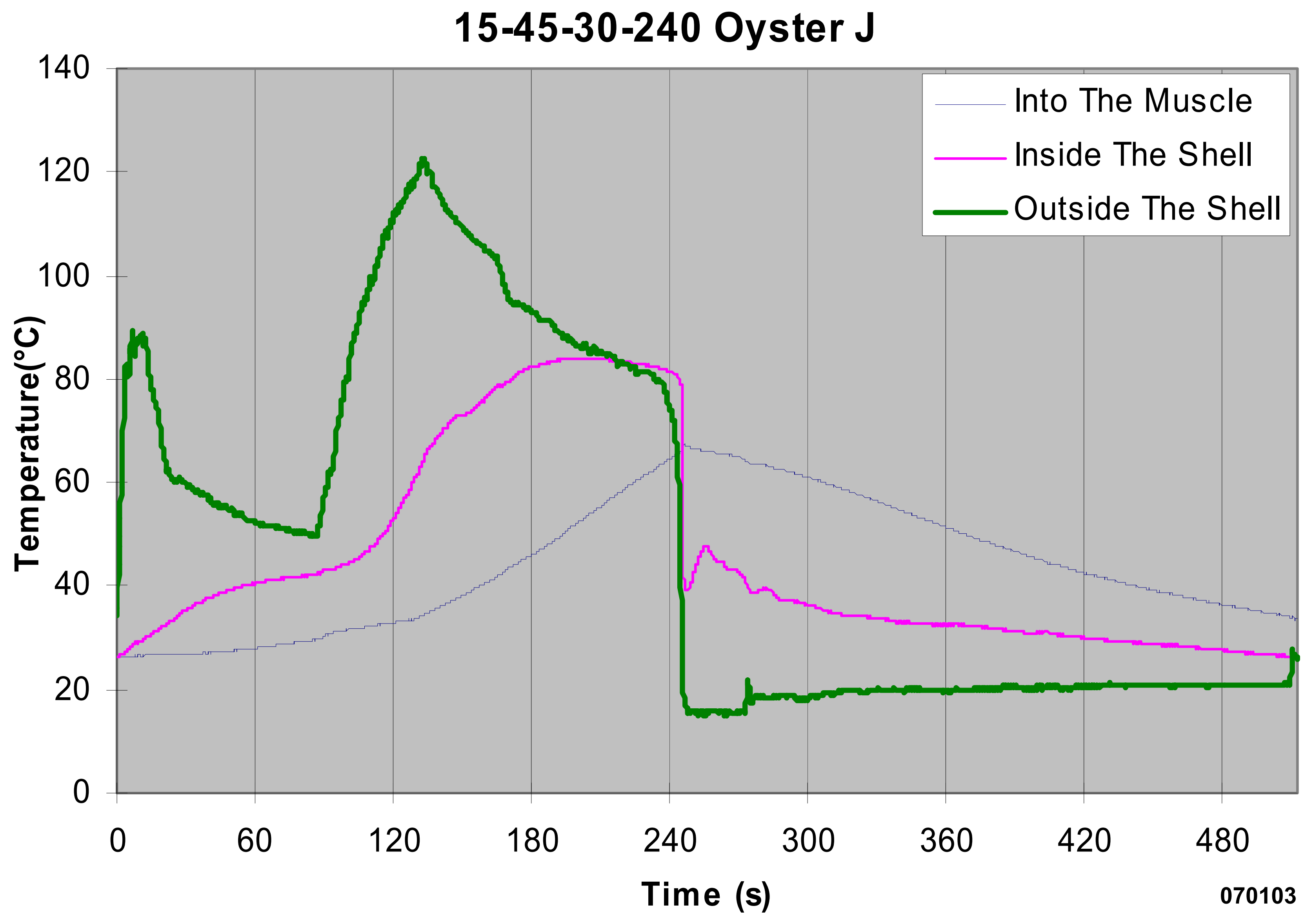

15-45-30-240 Oyster A
Into The Muscle
Inside The Shell
Outside the Shell
Temperature(°C)
0
20
40
60
80
100
120
140
Time (s)
0
60
120
180
240
300
360
420
070103

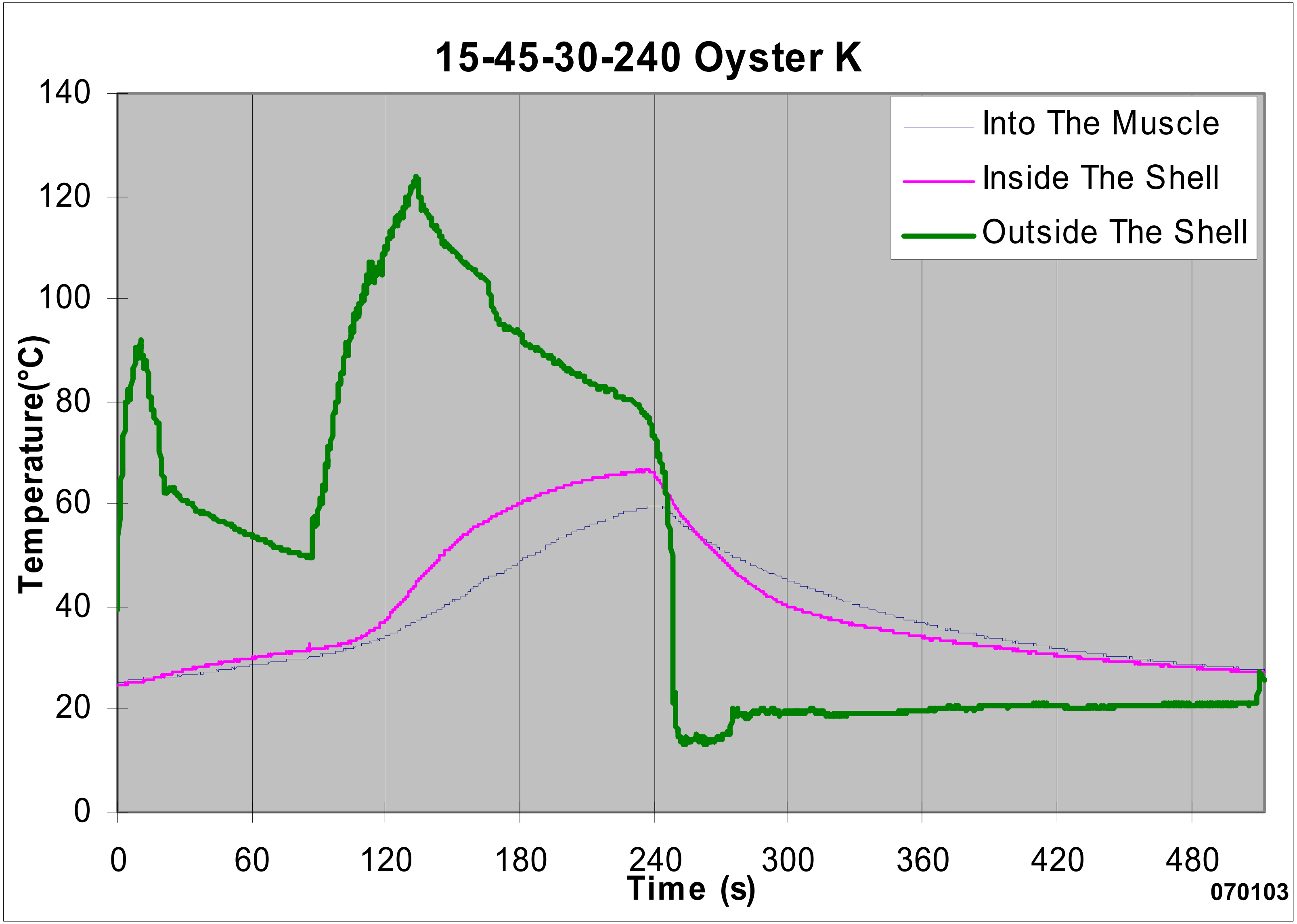


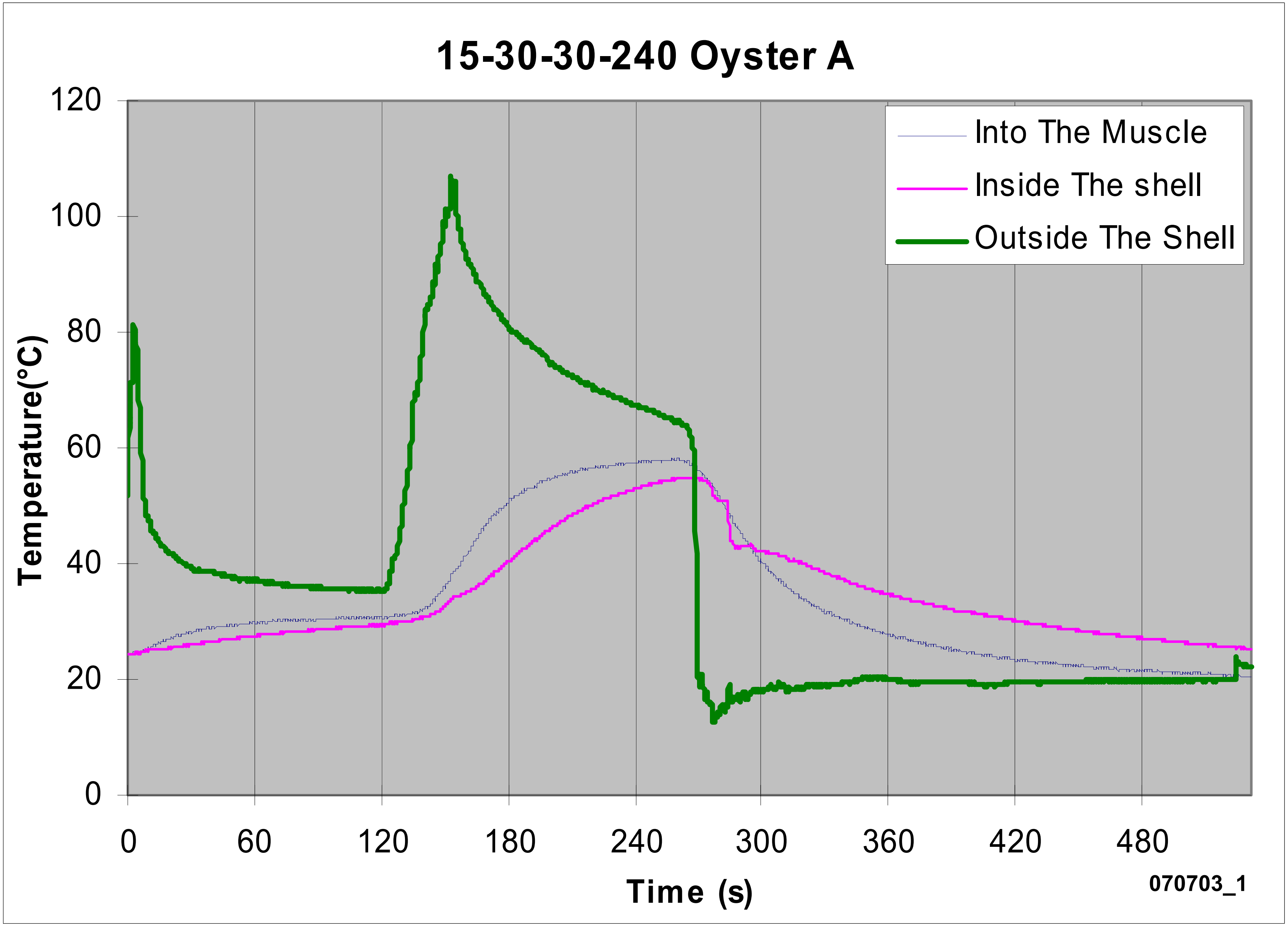
15-45-30-240 Oyster B

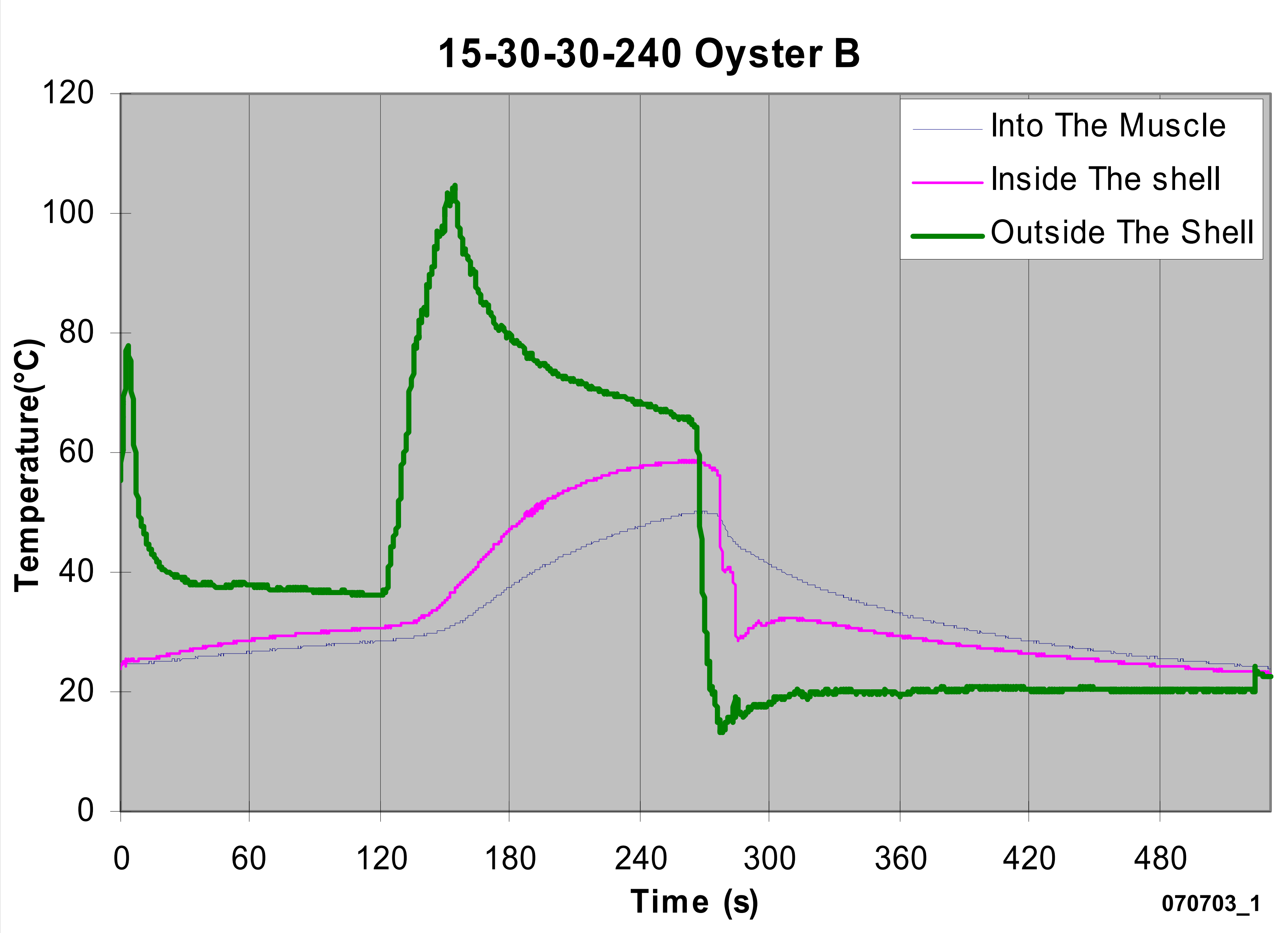

15-45-30-240 Oyster C
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
Time (s)
Into The Muscle
Inside The Shell
Outside the Shell
070103

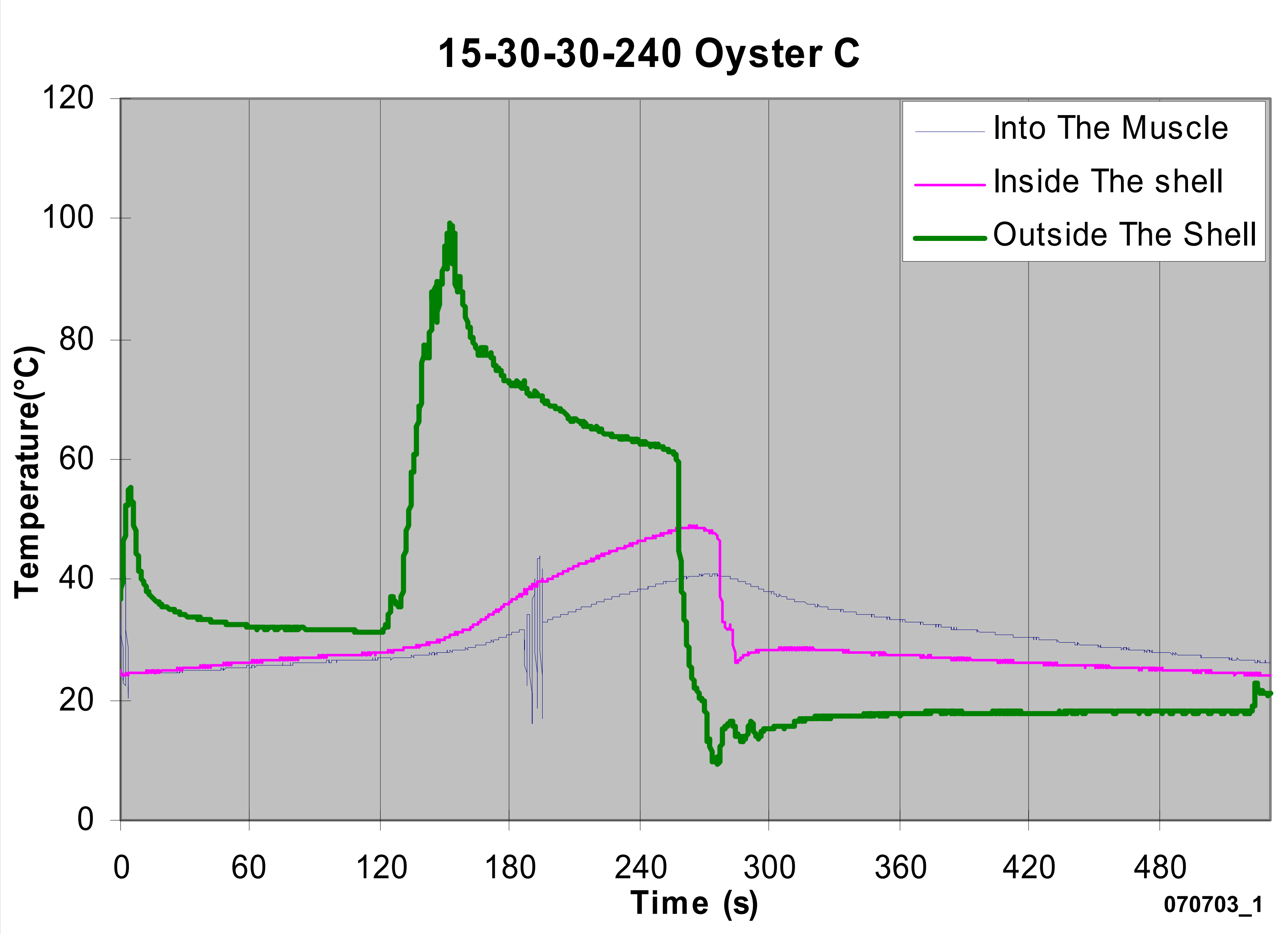

15-45-30-240 Oyster I
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Time (s)
070103
Into The Muscle
Inside The Shell
Outside The Shell

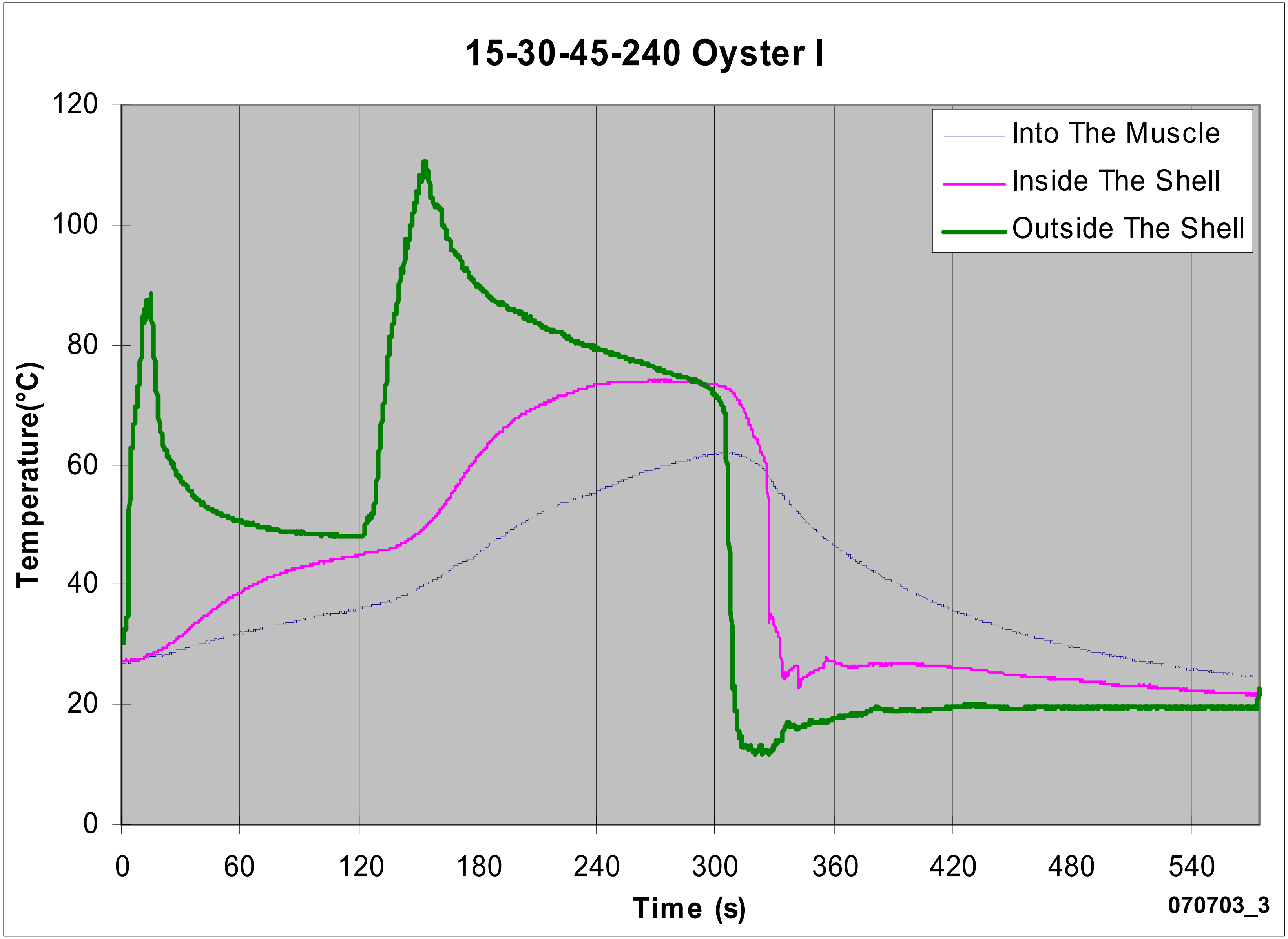

15-45-30-240 Oyster J
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
070103

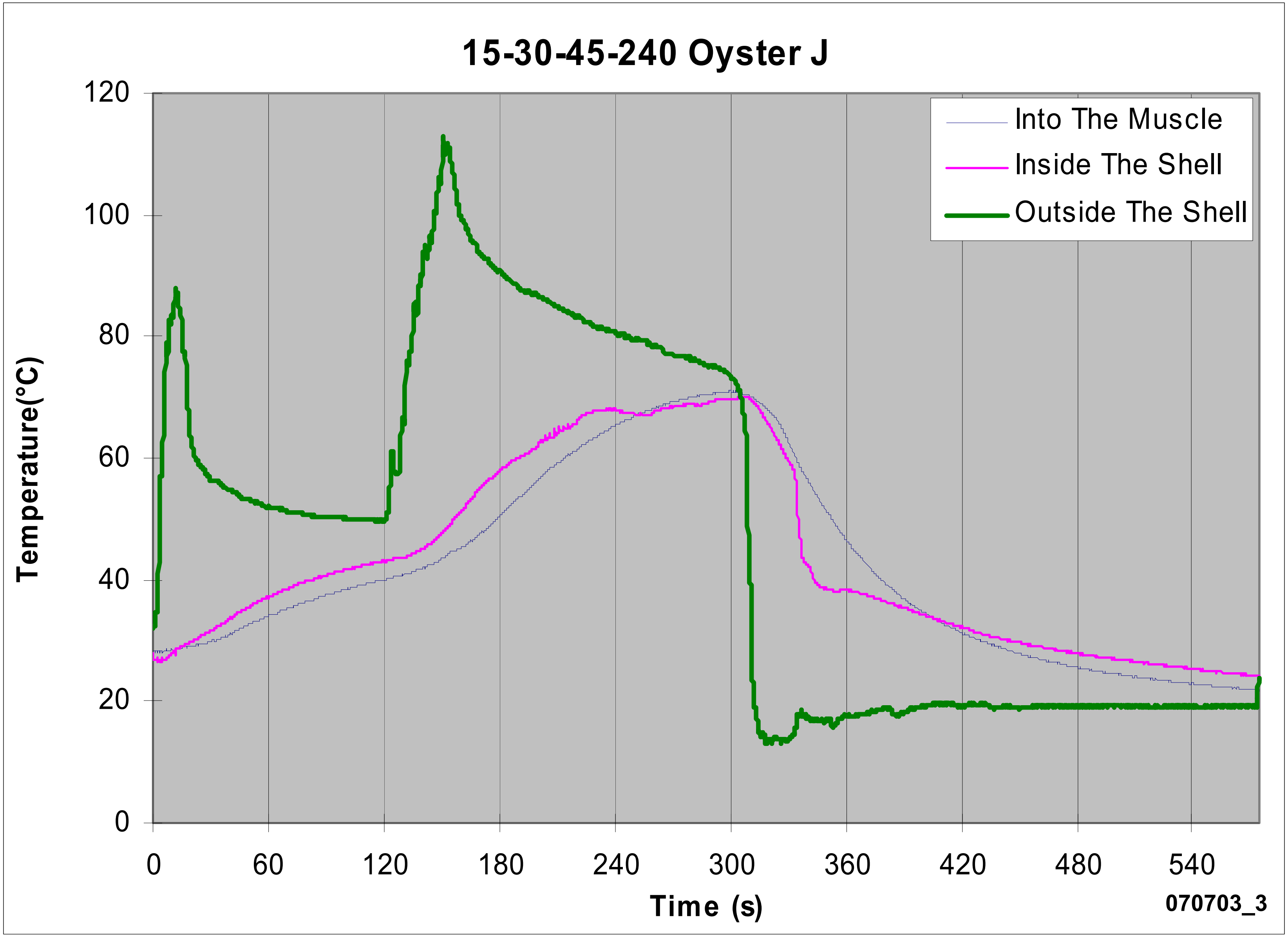

15-45-30-240 Oyster K
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
070103

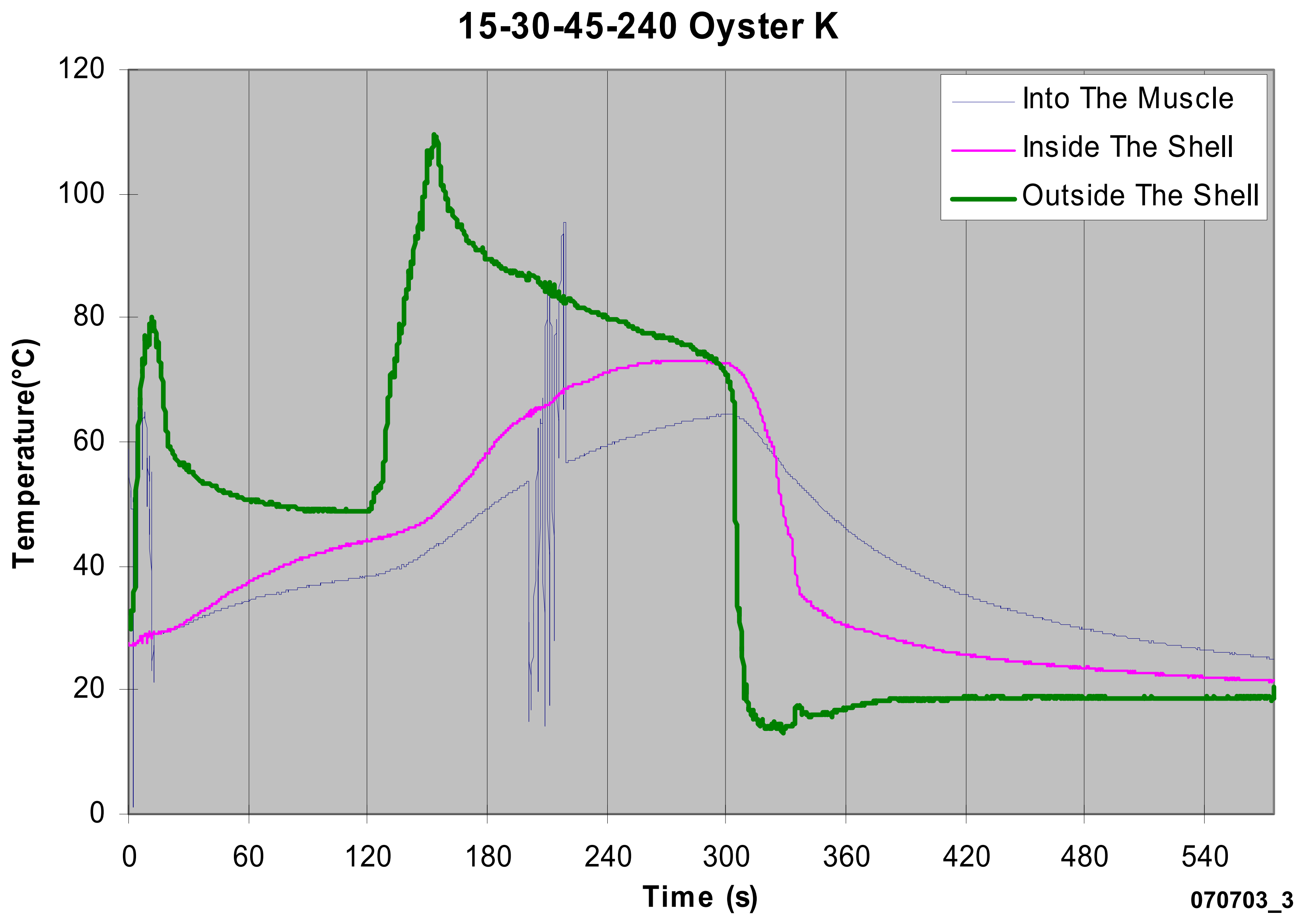

15-30-30-240 Oyster A
Into The Muscle
Inside The shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
480
070703_1

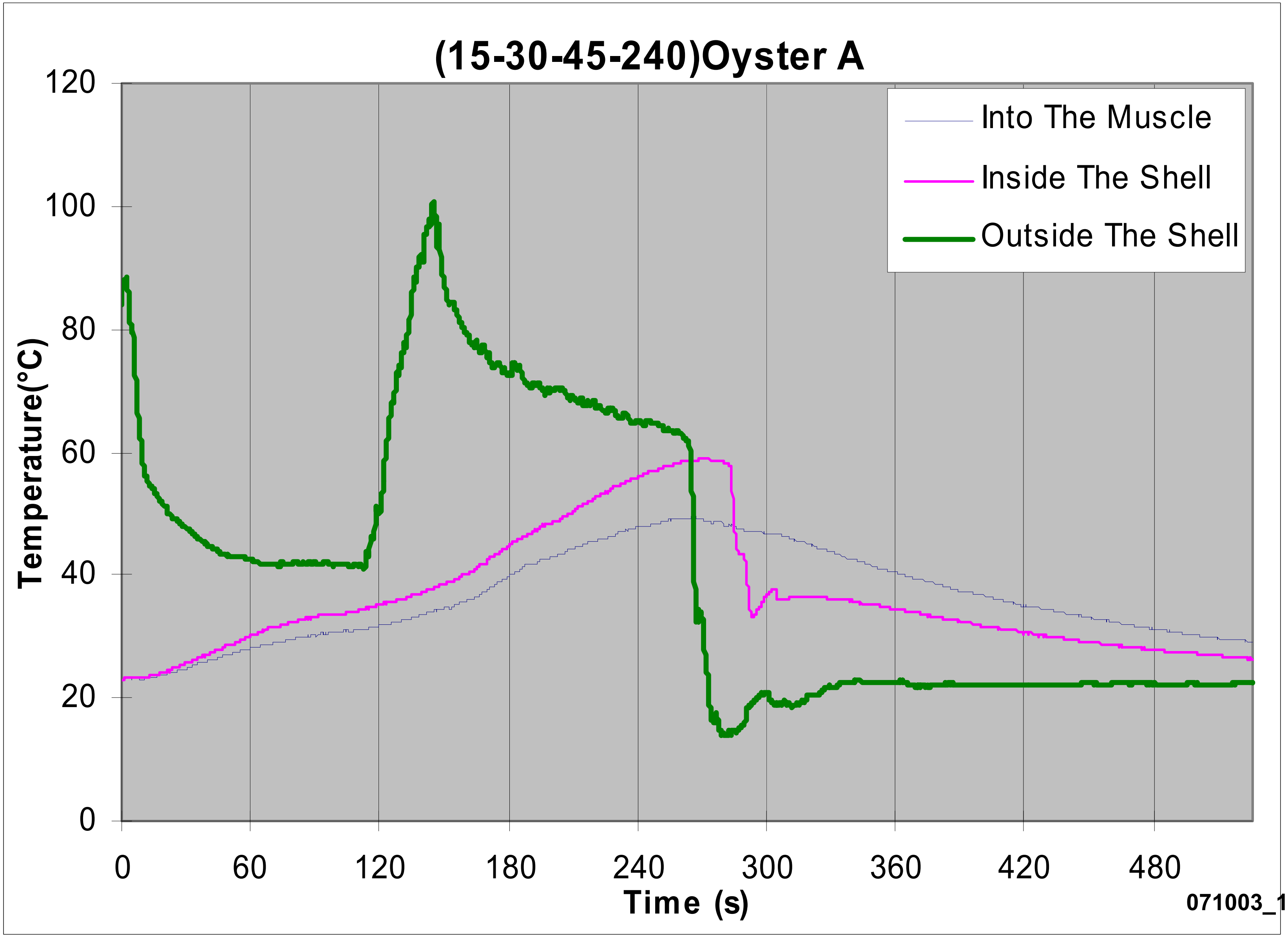

15-30-30-240 Oyster B
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Time (s)
Into The Muscle
Inside The shell
Outside The Shell
070703_1

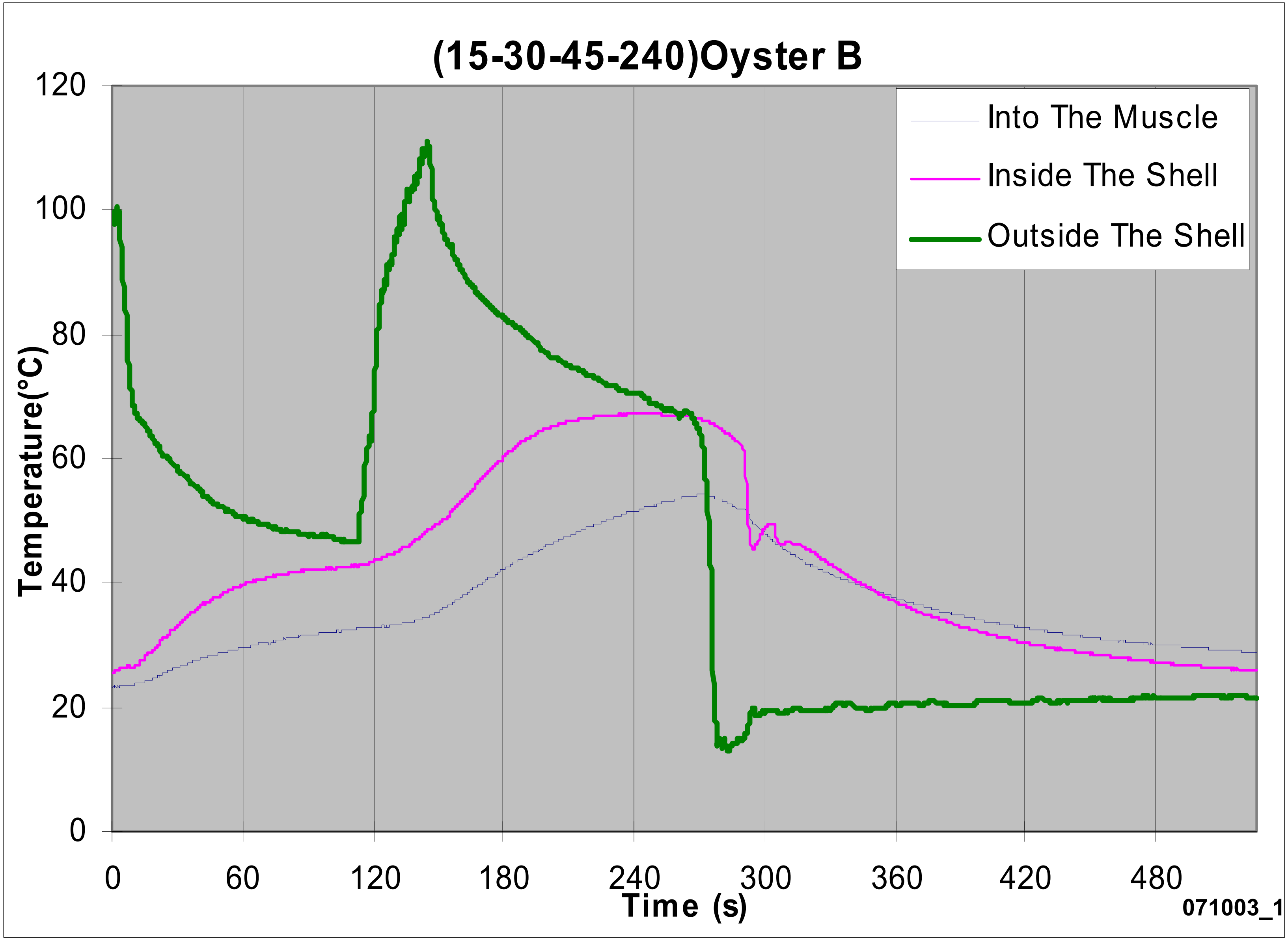

15-30-30-240 Oyster C
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Time (s)
Into The Muscle
Inside The shell
Outside The Shell
070703_1

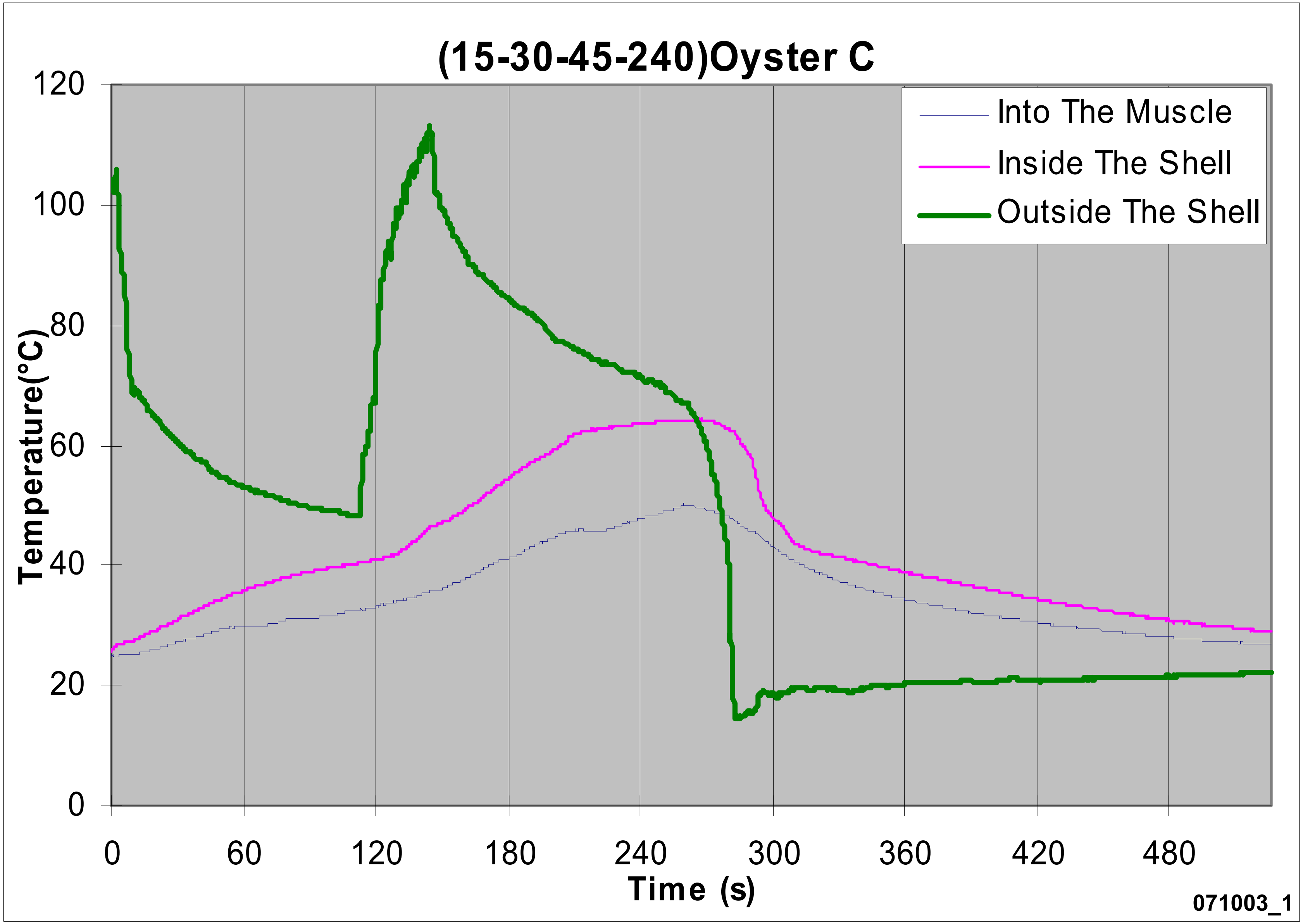

15-30-45-240 Oyster I
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
070703_3

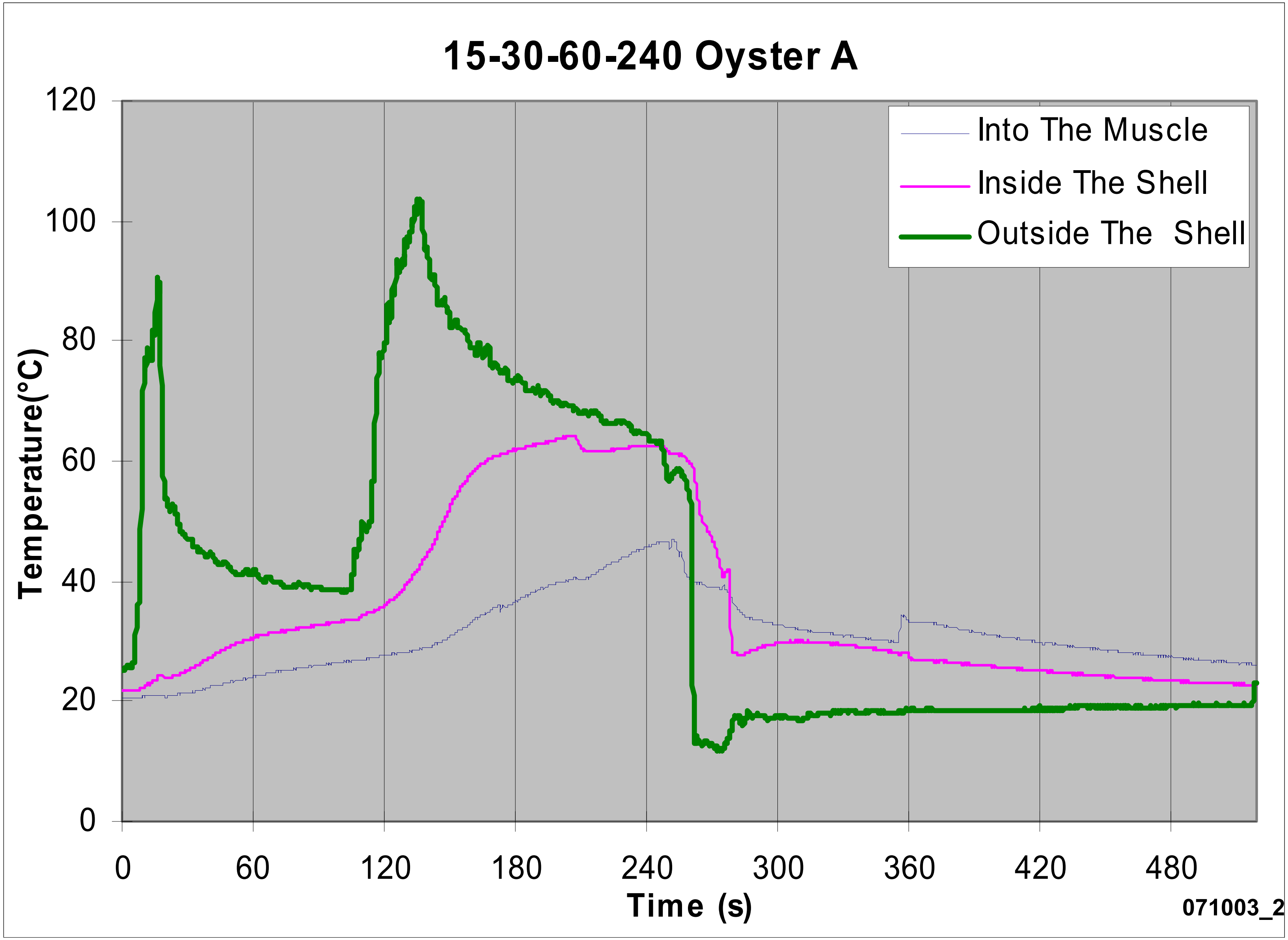

15-30-45-240 Oyster J
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
070703_3

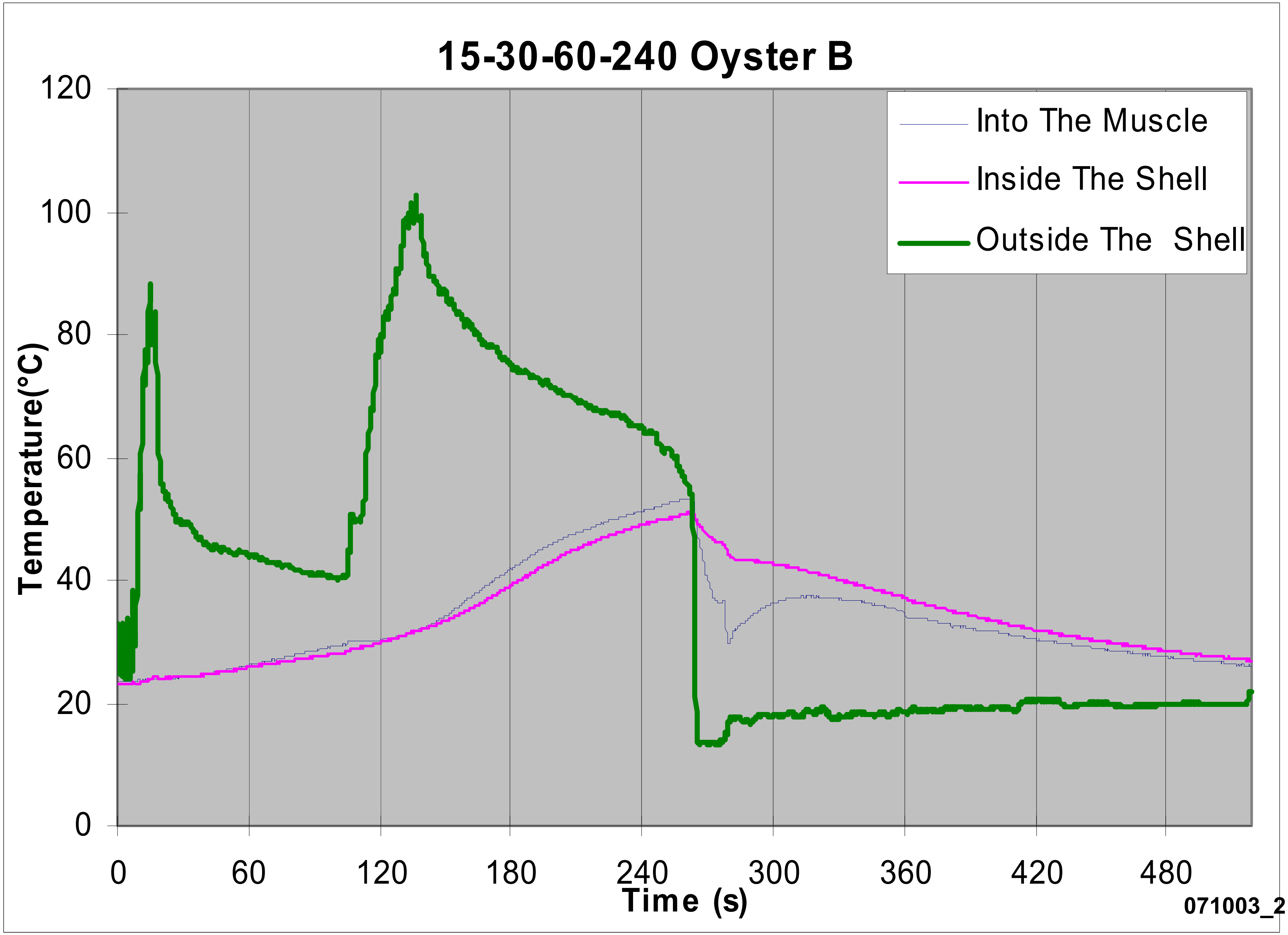

15-30-45-240 Oyster K
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
070703_3

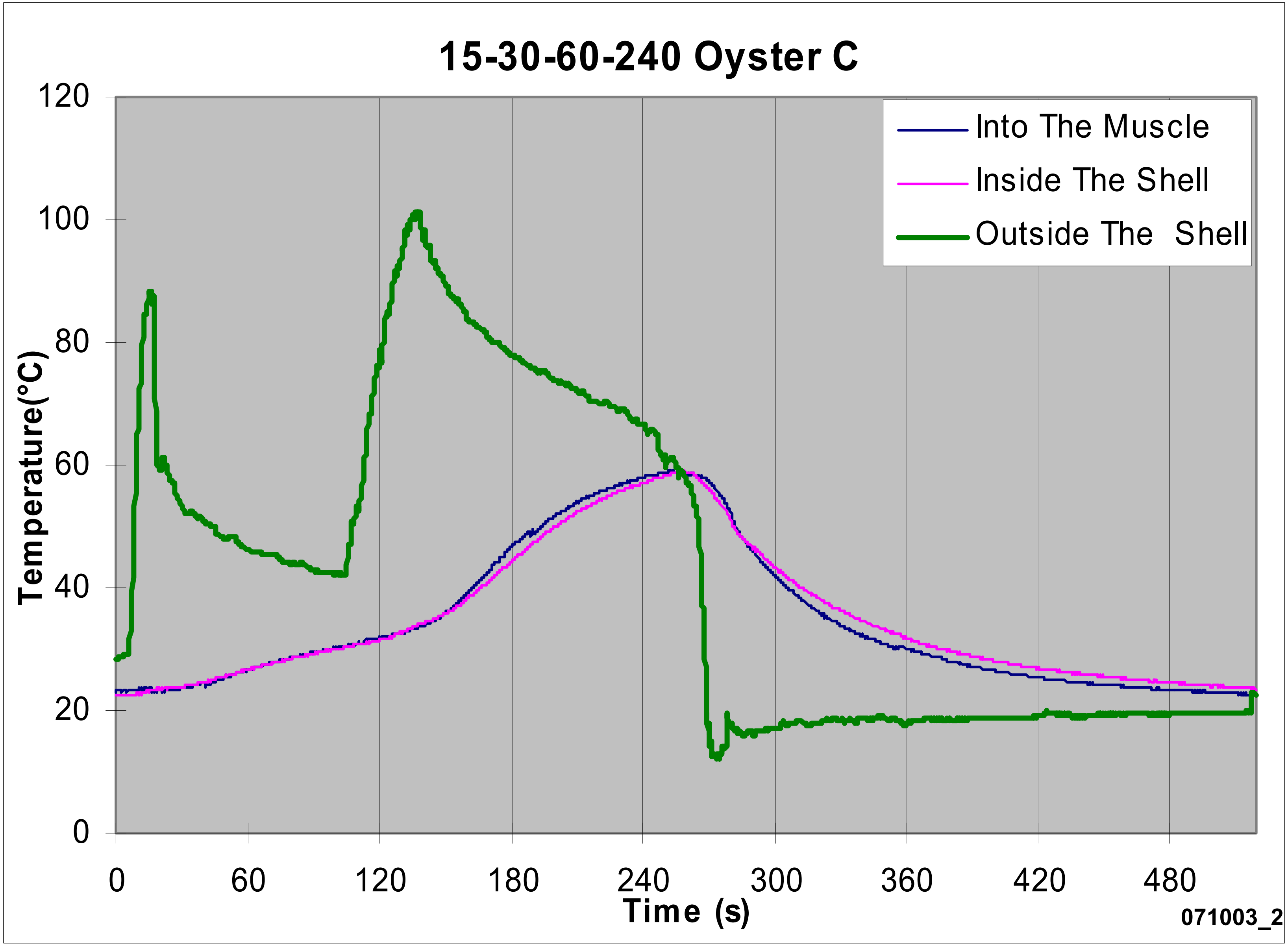

(15-30-45-240)Oyster A
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
480
Into The Muscle
Inside The Shell
Outside The Shell
071003_1

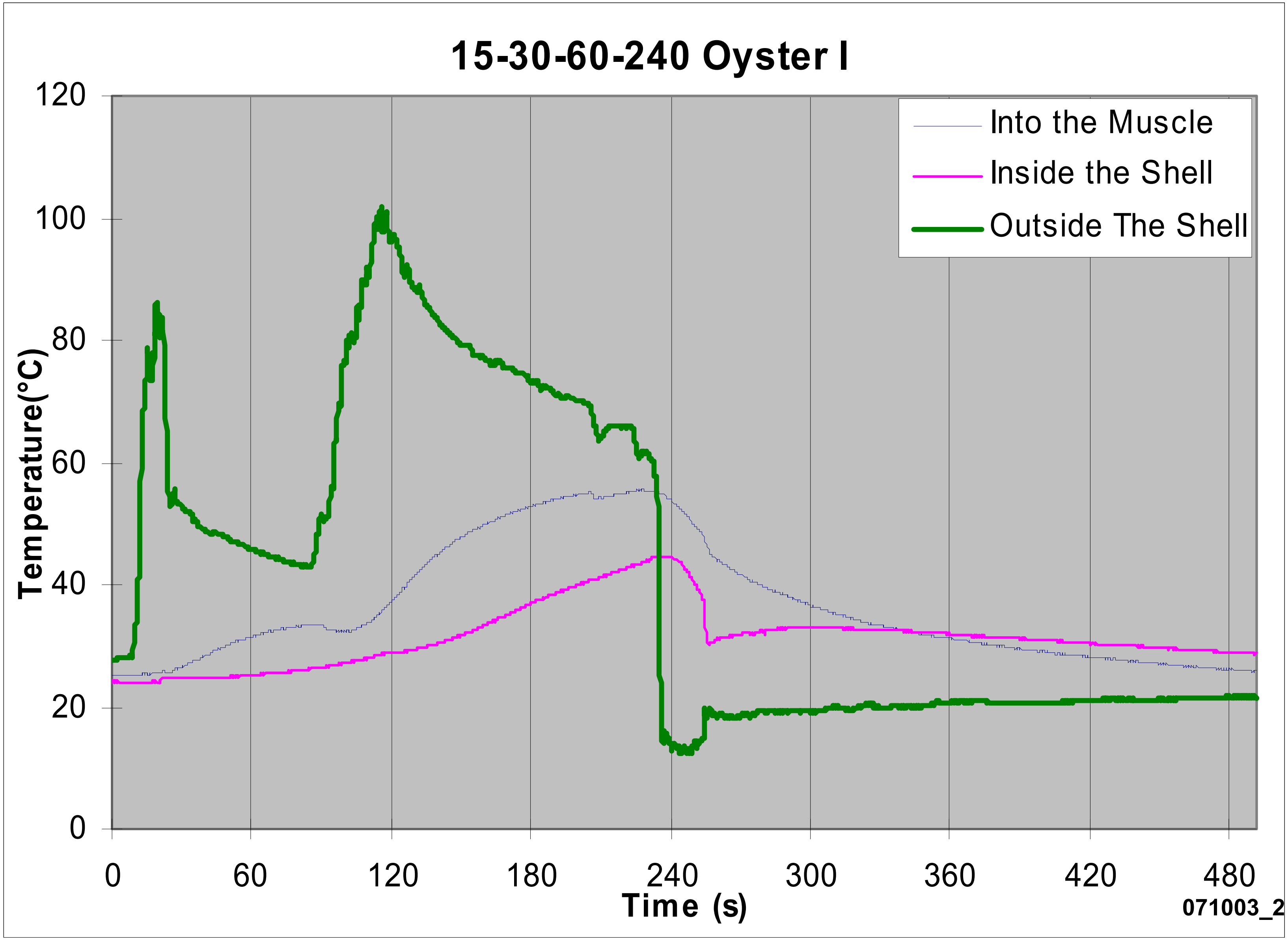

(15-30-45-240)Oyster B
Temperature(°C)
0
20
40
60
80
100
120
0
60
120
180
240
300
360
420
480
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
071003_1

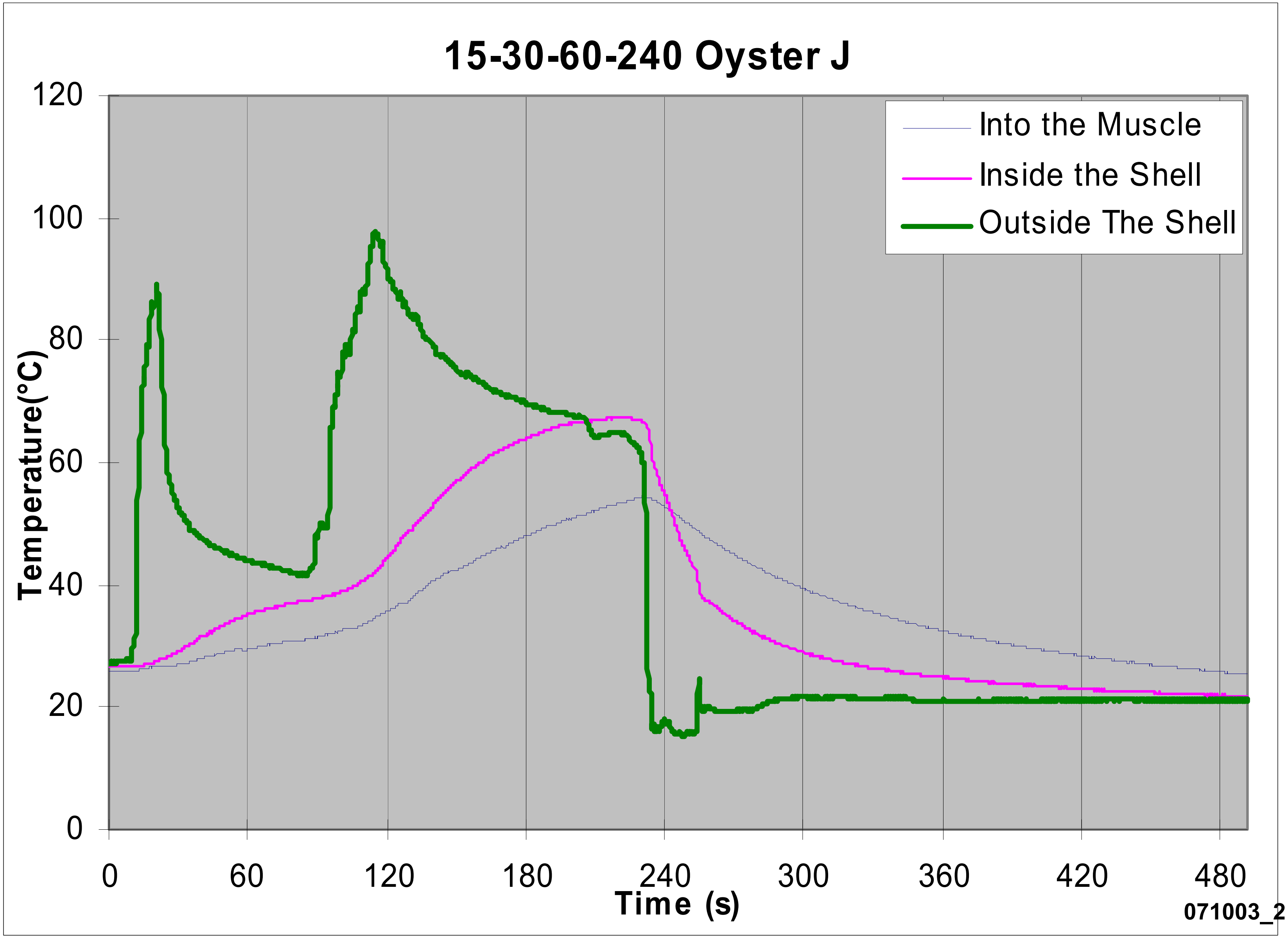

(15-30-45-240)Oyster C
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
480
071003_1

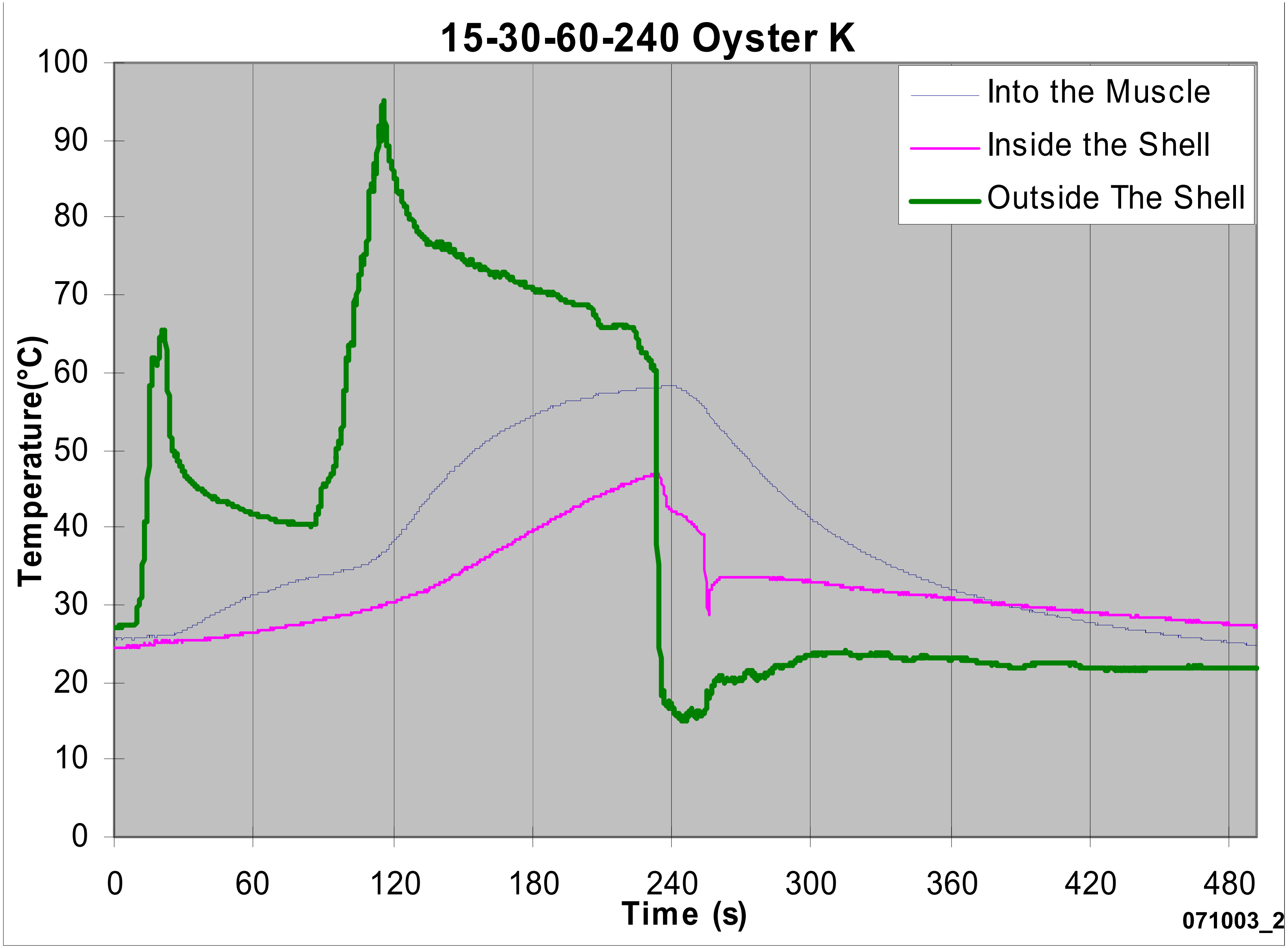

15-30-60-240 Oyster A
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
0
60
120
180
240
300
360
420
480
Time (s)
071003_2

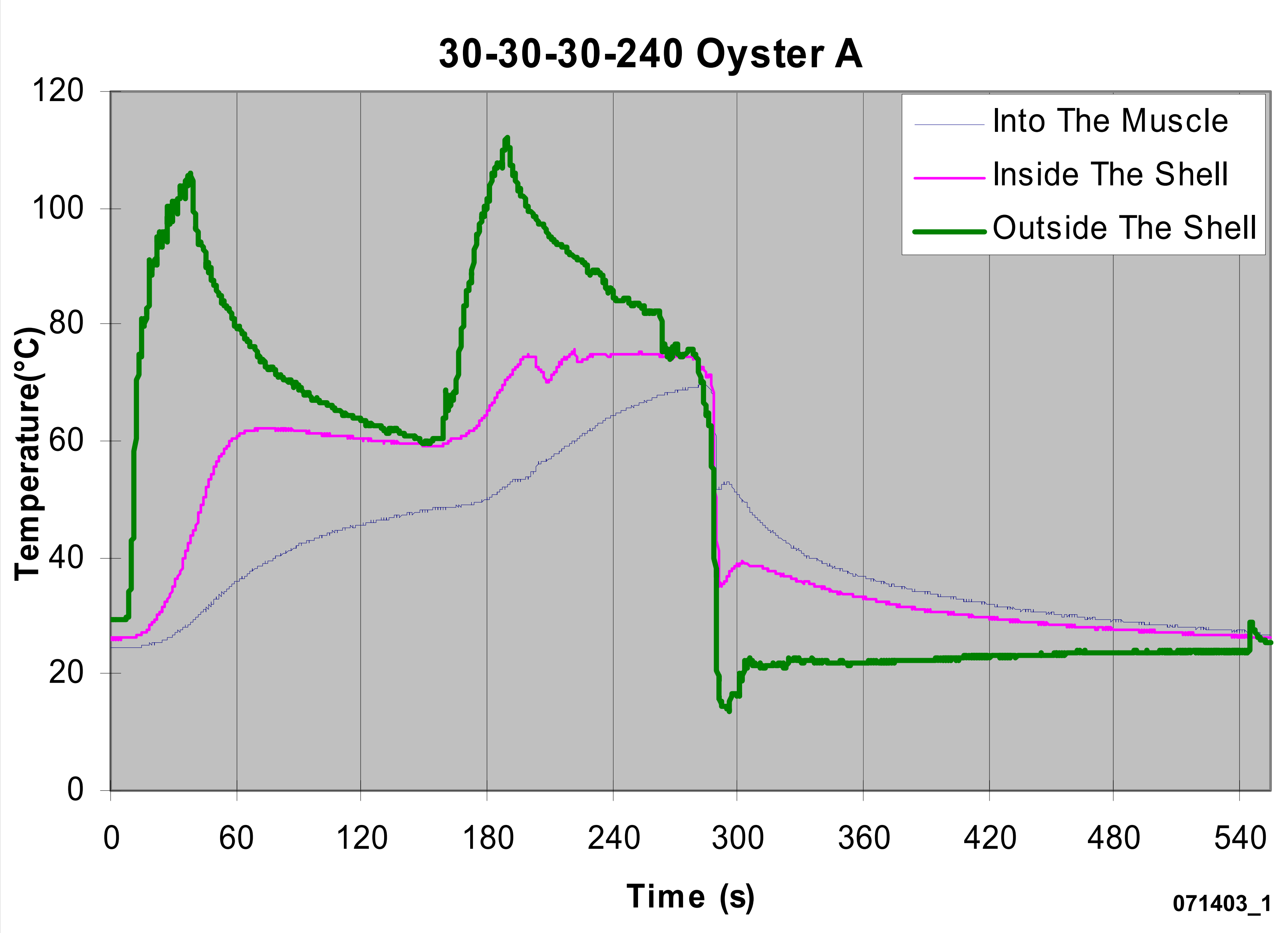

15-30-60-240 Oyster B
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
480
Into The Muscle
Inside The Shell
Outside The Shell
071003_2

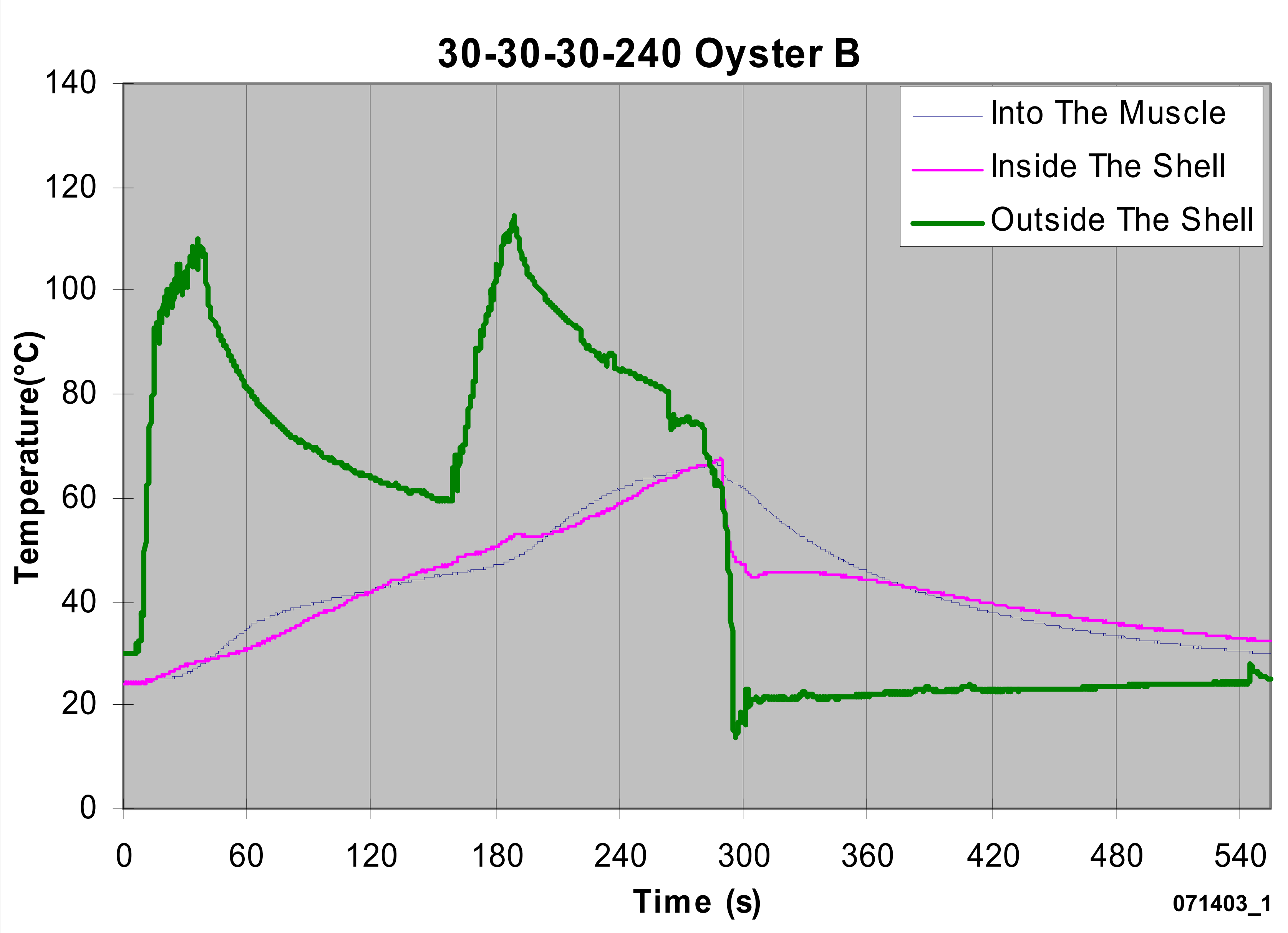

15-30-60-240 Oyster C
Temperature(°C)
0
20
40
60
80
100
120
Time (s)
0
60
120
180
240
300
360
420
480
Into The Muscle
Inside The Shell
Outside The Shell
071003_2

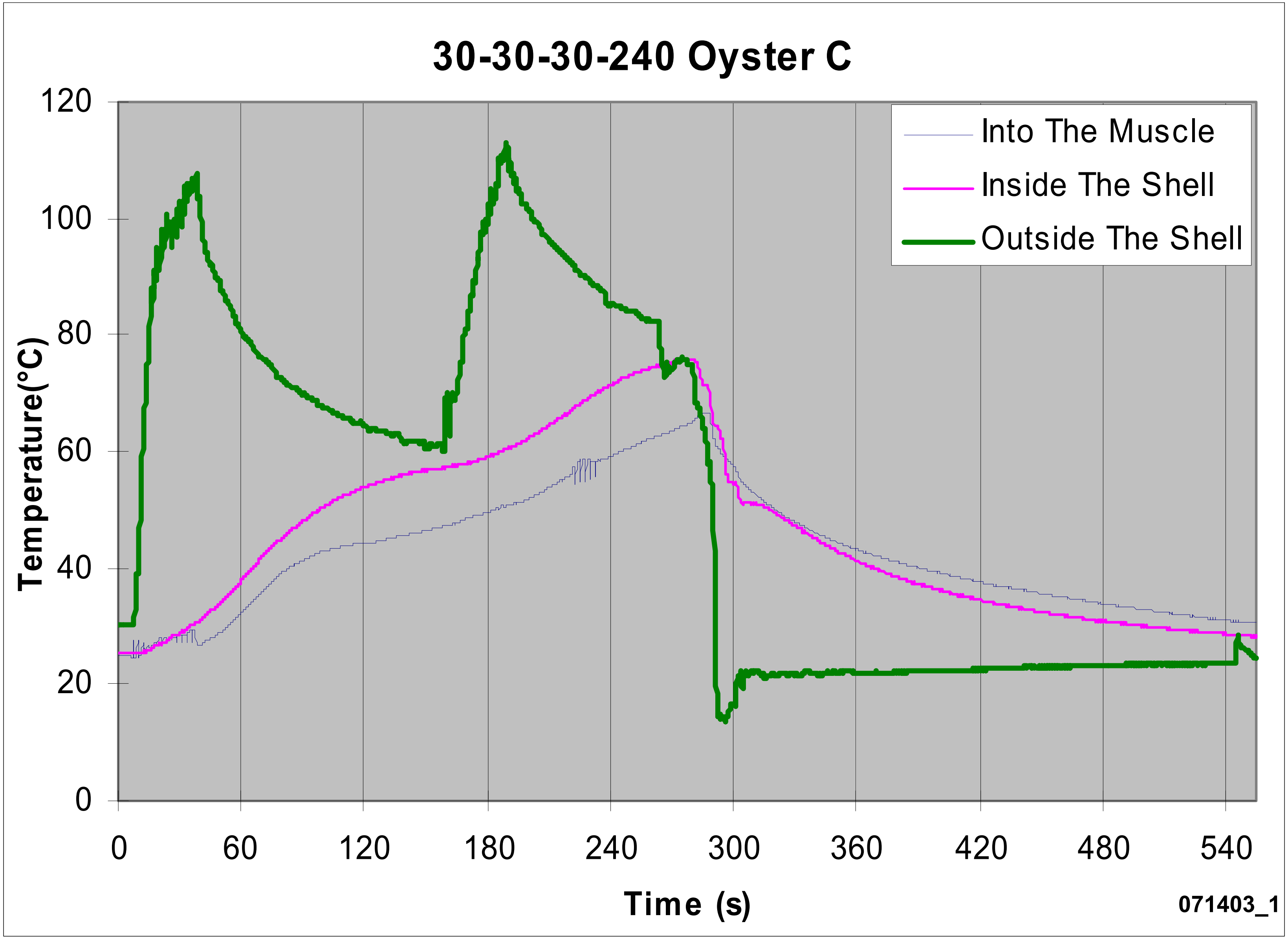

15-30-60-240 Oyster I
Temperature(°C)
0
20
40
60
80
100
120
0
60
120
180
240
300
360
420
480
Time (s)
Into the Muscle
Inside the Shell
Outside The Shell
071003_2

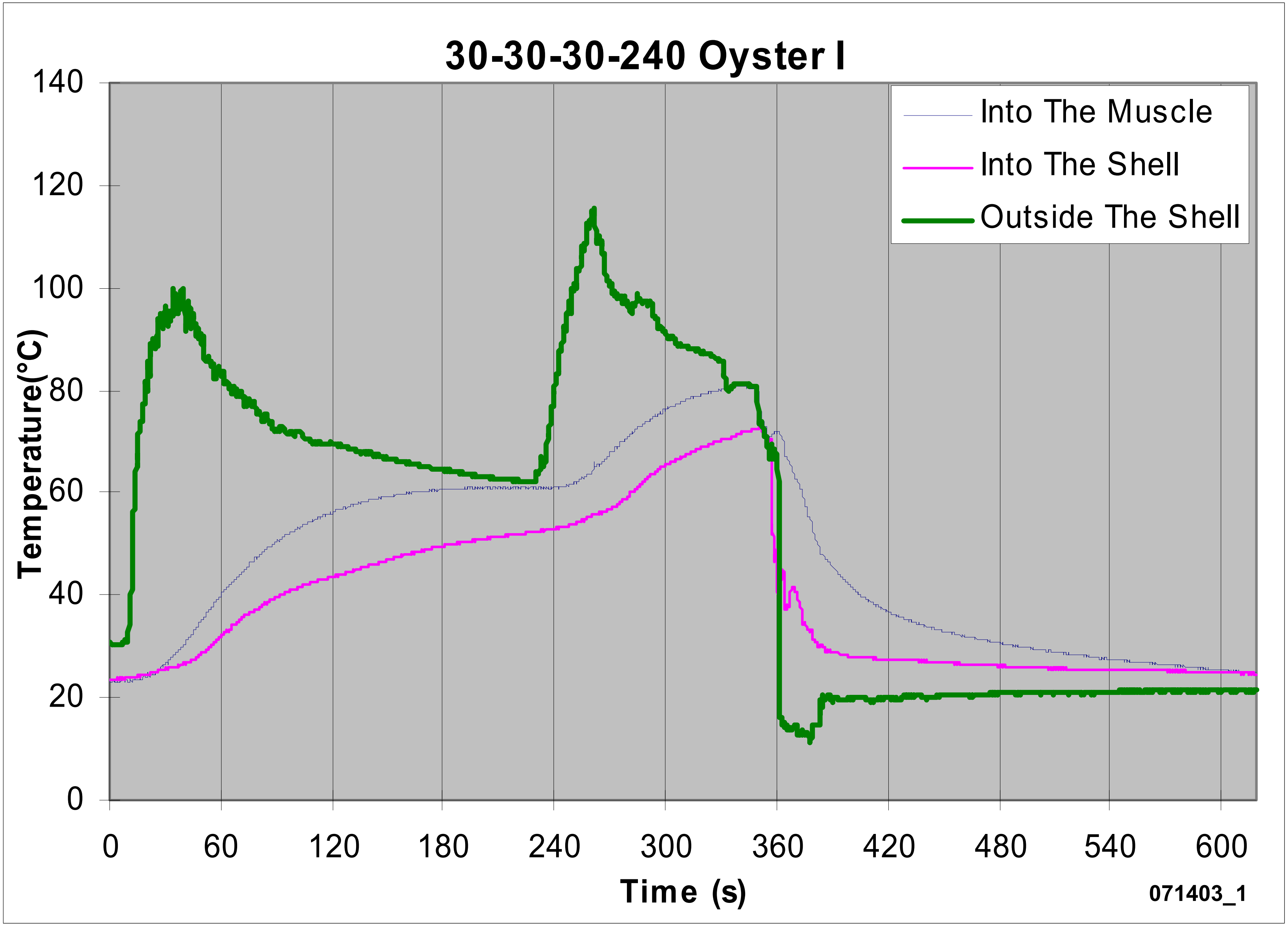

15-30-60-240 Oyster J
120
100
80
60
40
20
0
Temperature(°C)
0
60
120
180
240
300
360
420
480
Time (s)
Into the Muscle
Inside the Shell
Outside The Shell
071003_2

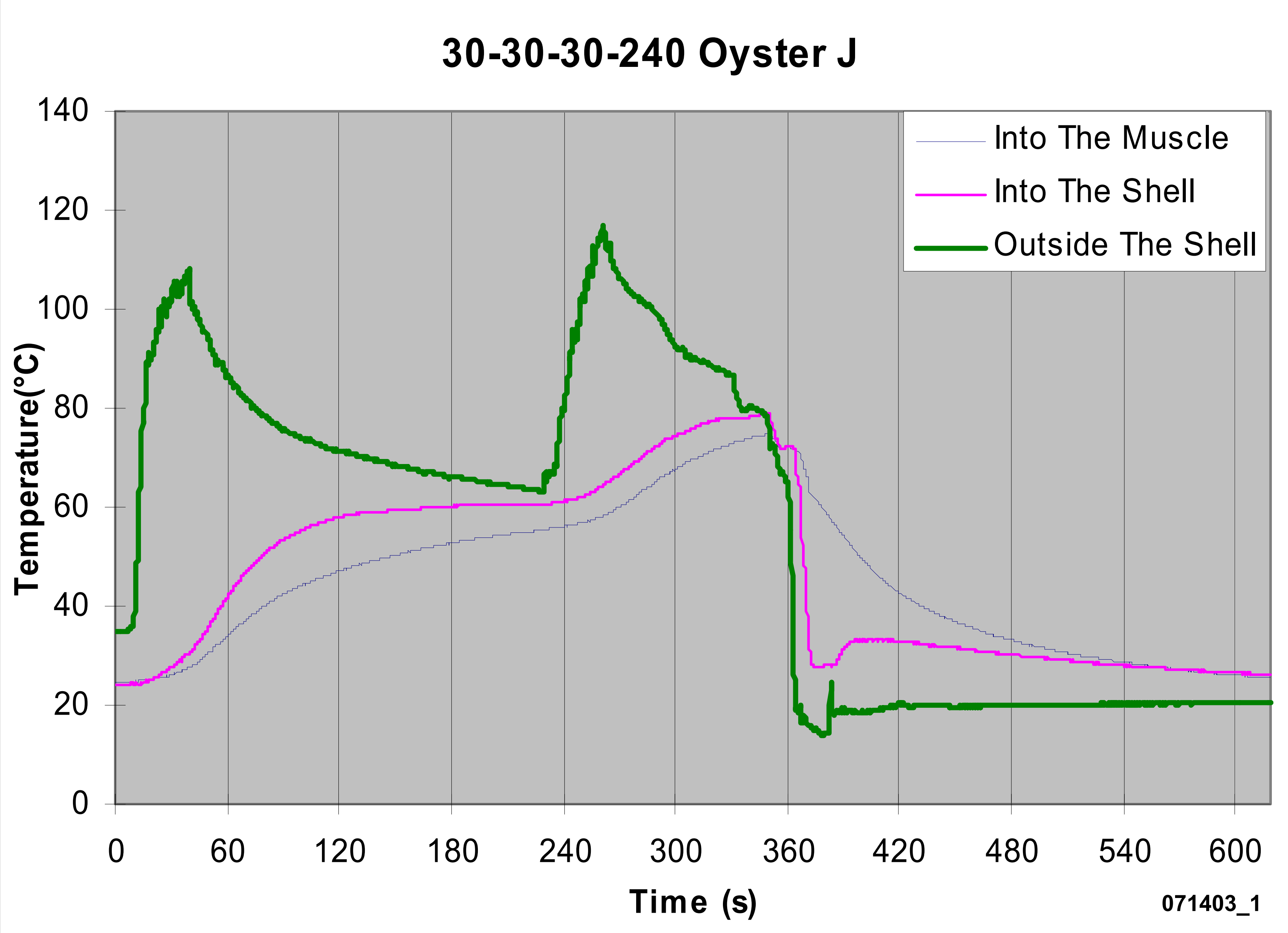

15-30-60-240 Oyster K
Temperature(°C)
100
90
80
70
60
50
40
30
20
10
0
0
60
120
180
240
300
360
420
480
Time (s)
Into the Muscle
Inside the Shell
Outside The Shell
071003_2

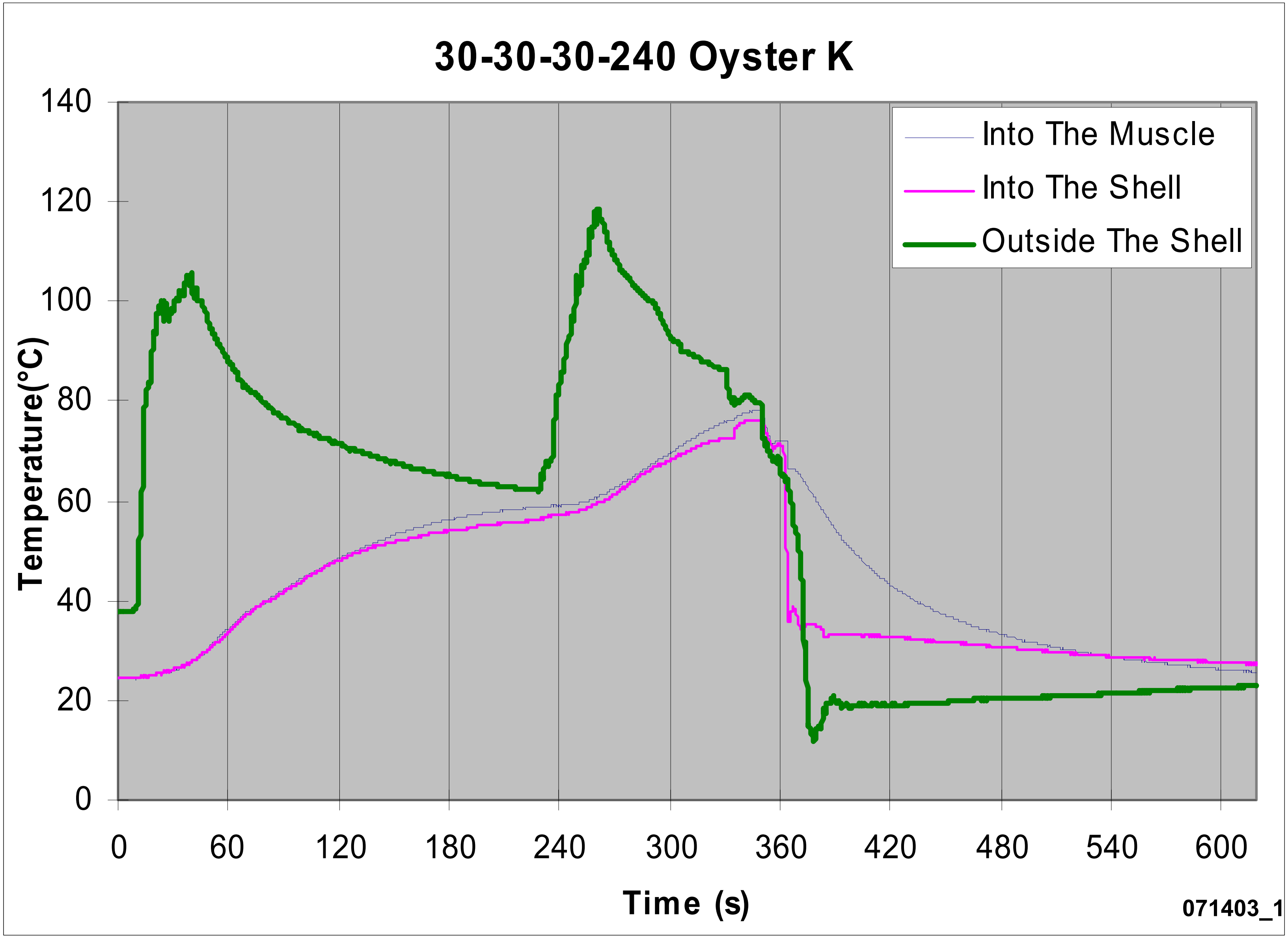

30-30-30-240 Oyster A
Into The Muscle
Inside The Shell
Outside The Shell
Temperature(°C)
0
20
40
60
80
100
120
0
60
120
180
240
300
360
420
480
540
Time (s)
071403_1

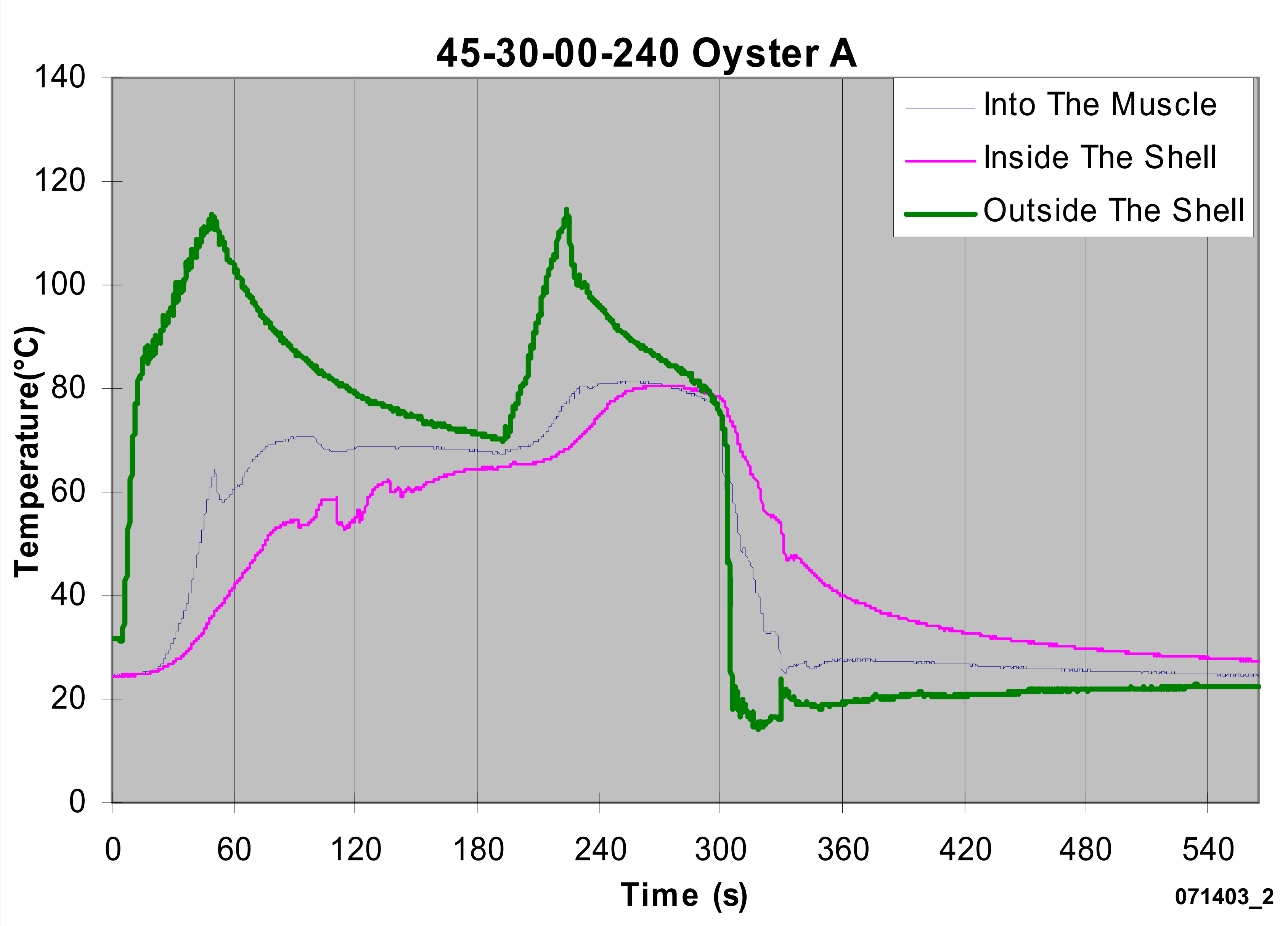

30-30-30-240 Oyster B
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
071403_1

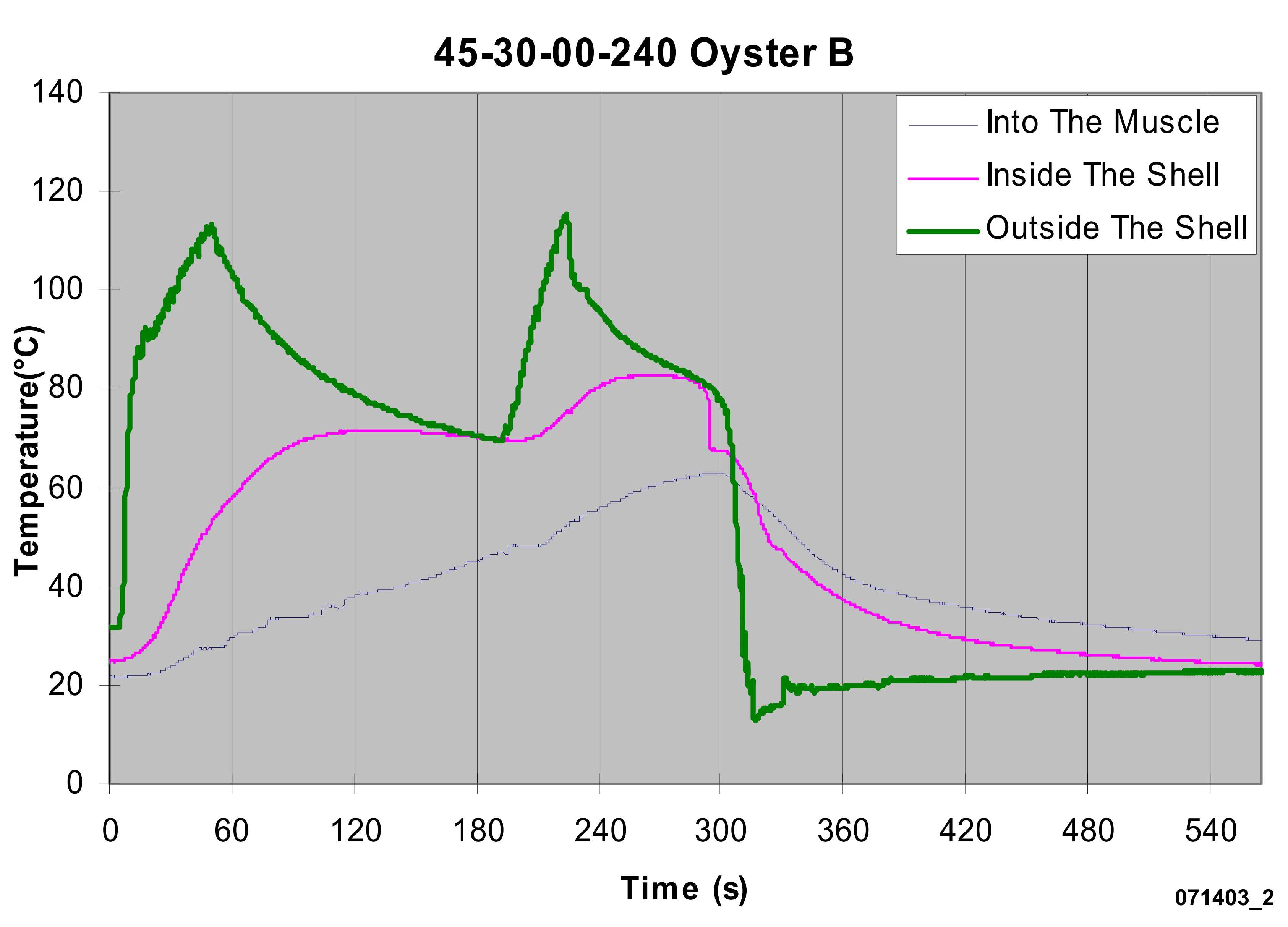

30-30-30-240 Oyster C
Temperature(°C)
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
071403_1

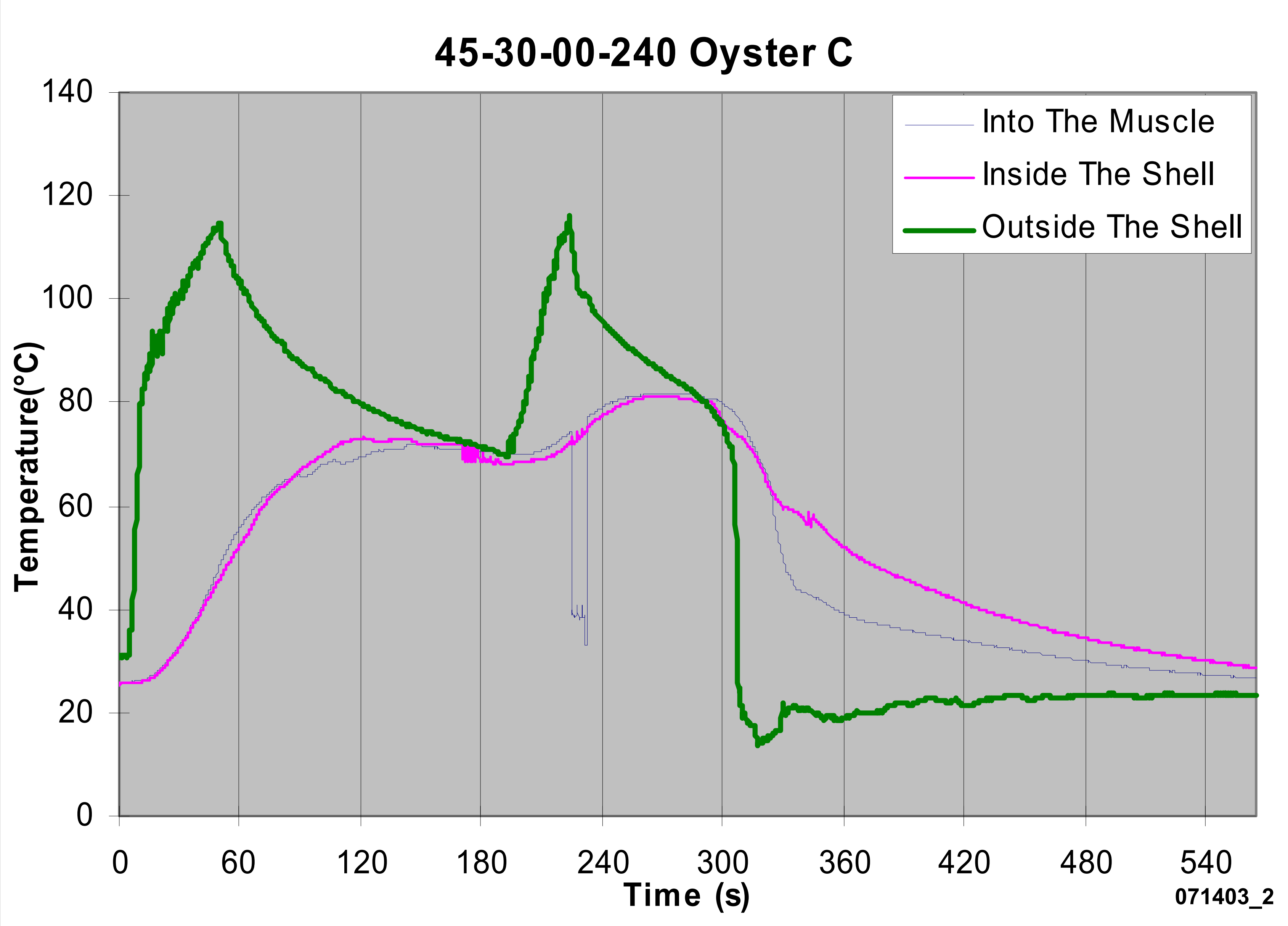

30-30-30-240 Oyster I
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Into The Shell
Outside The Shell
071403_1

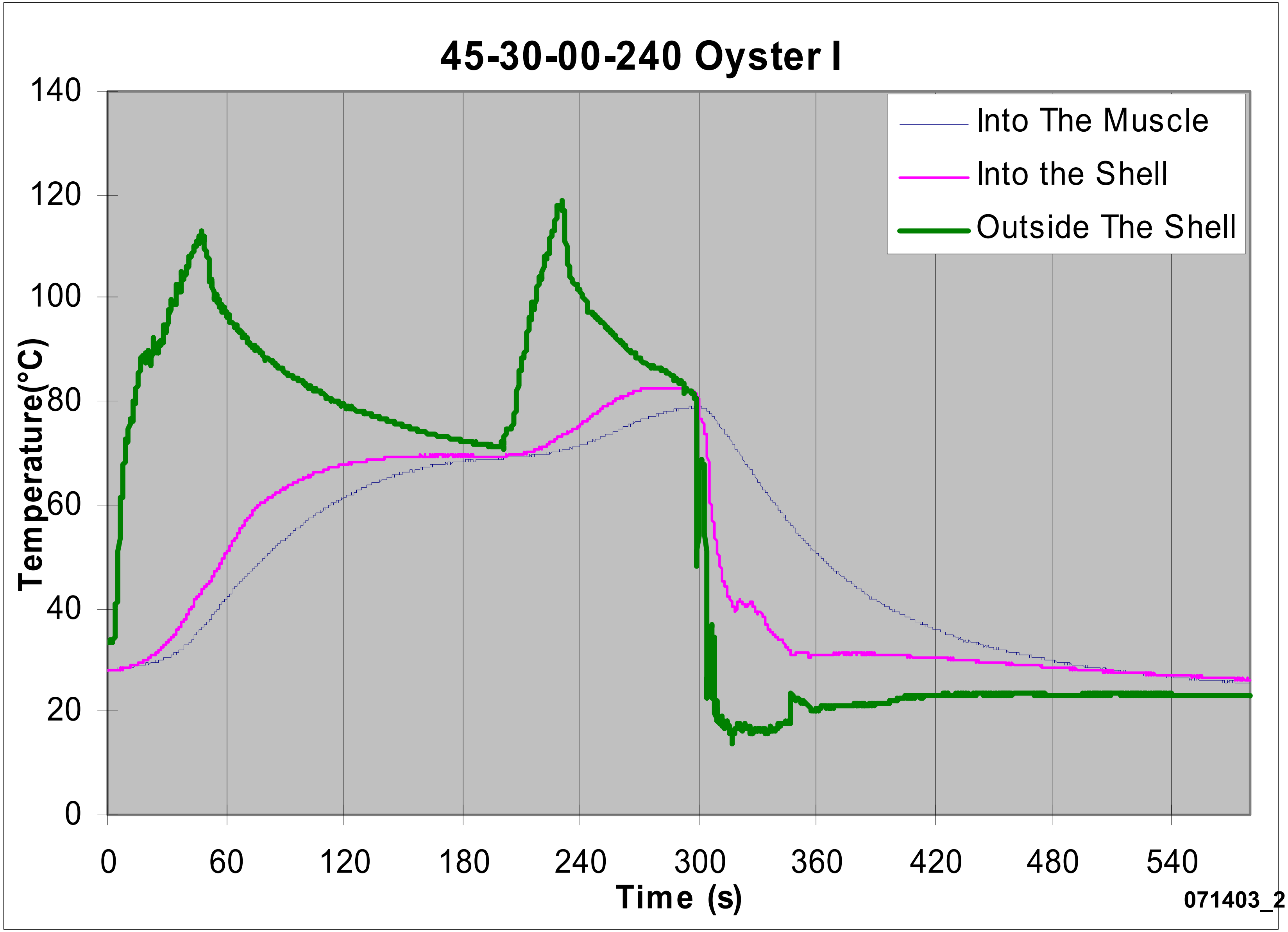

30-30-30-240 Oyster J
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Into The Shell
Outside The Shell
071403_1

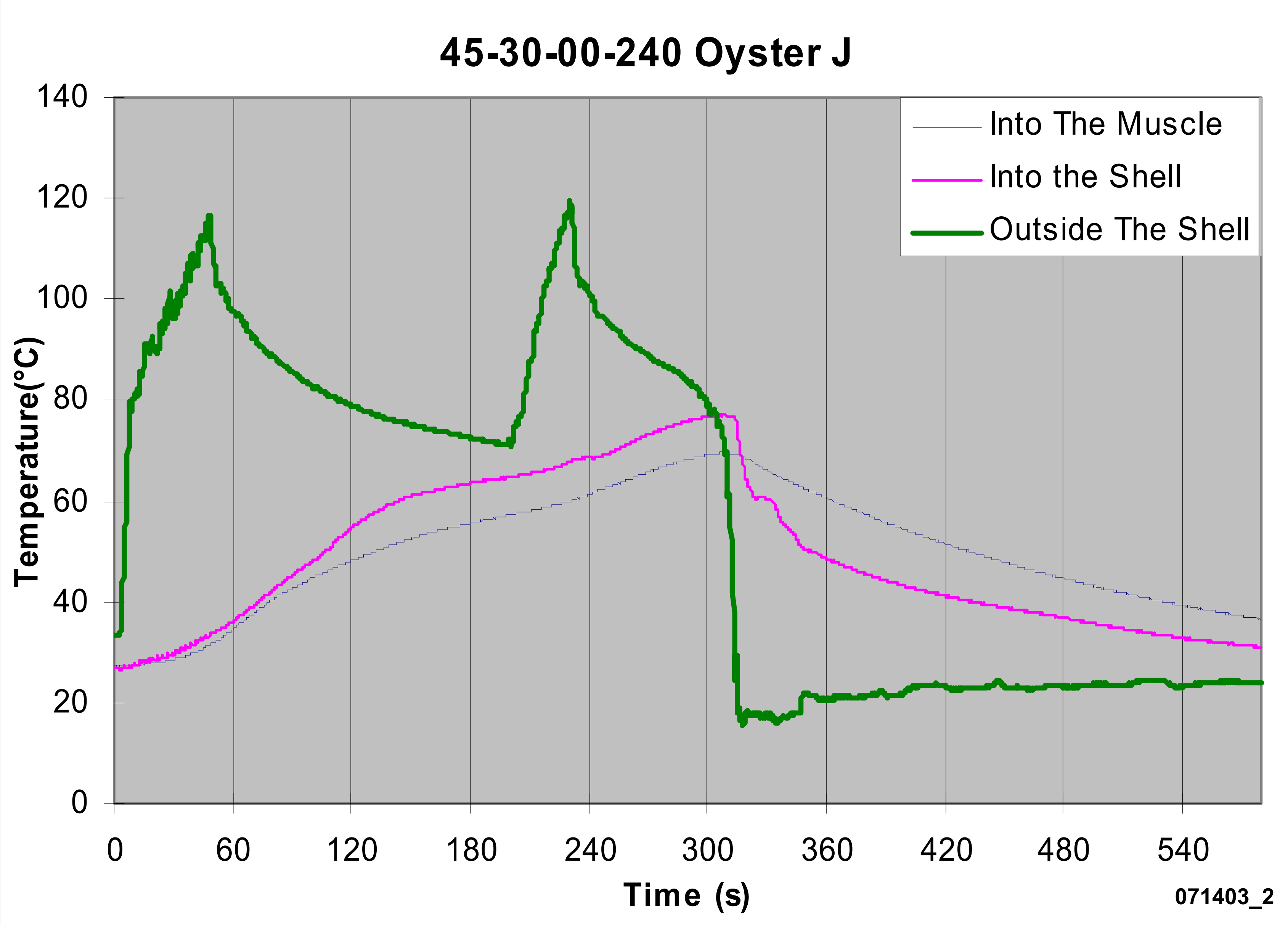

30-30-30-240 Oyster K
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
Time (s)
Into The Muscle
Into The Shell
Outside The Shell
071403_1

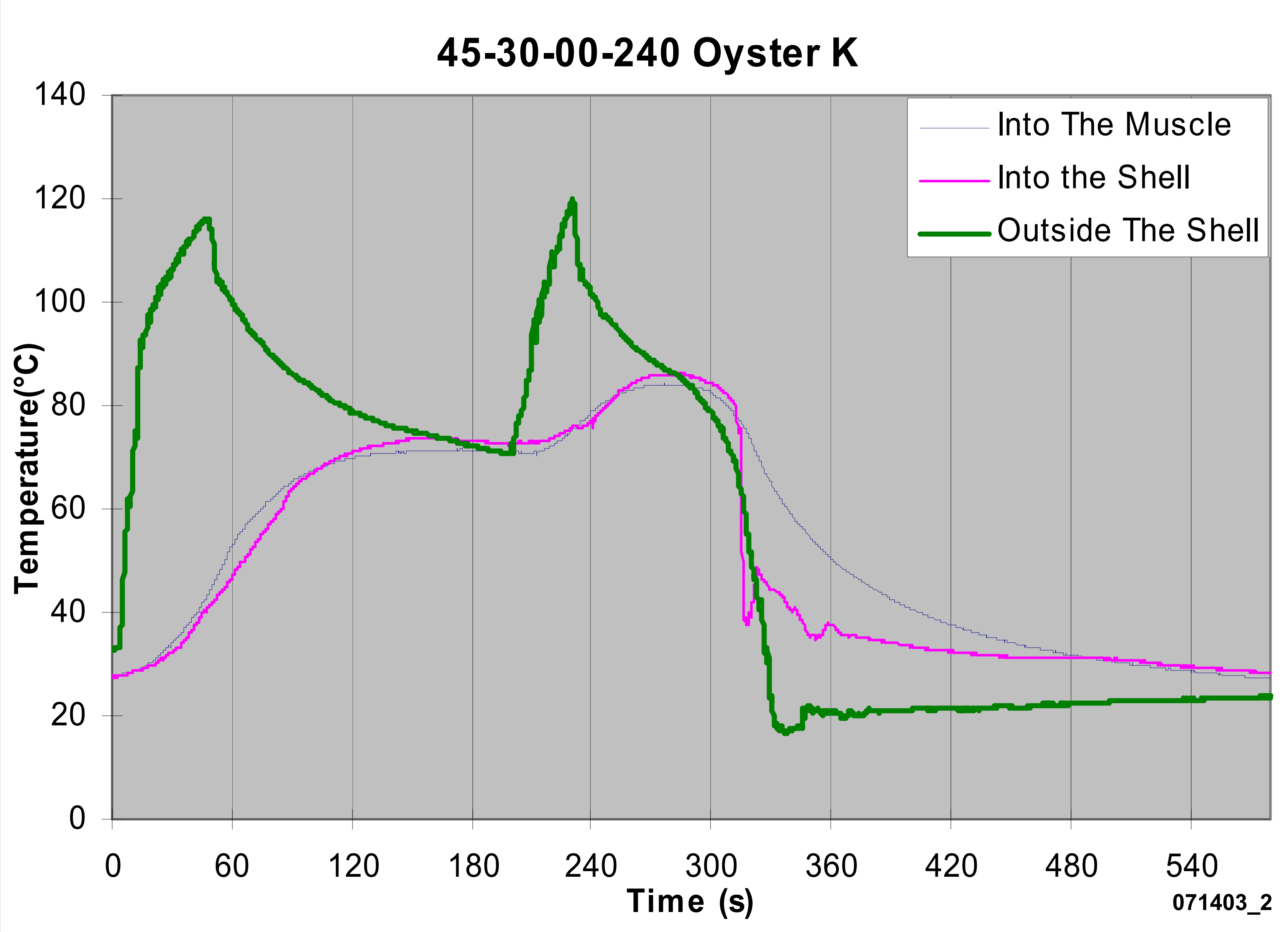

45-30-00-240 Oyster A
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
071403_2


45-30-00-240 Oyster B
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
Into The Muscle
Inside The Shell
Outside The Shell
071403_2


45-30-00-240 Oyster C
Temperature(°C)
0
20
40
60
80
100
120
140
Time (s)
0
60
120
180
240
300
360
420
480
540
Into The Muscle
Inside The Shell
Outside The Shell
071403_2


45-30-00-240 Oyster I
Into The Muscle
Into the Shell
Outside The Shell
Temperature(°C)
Time (s)
0
20
40
60
80
100
120
140
0
60
120
180
240
300
360
420
480
540
071403_2

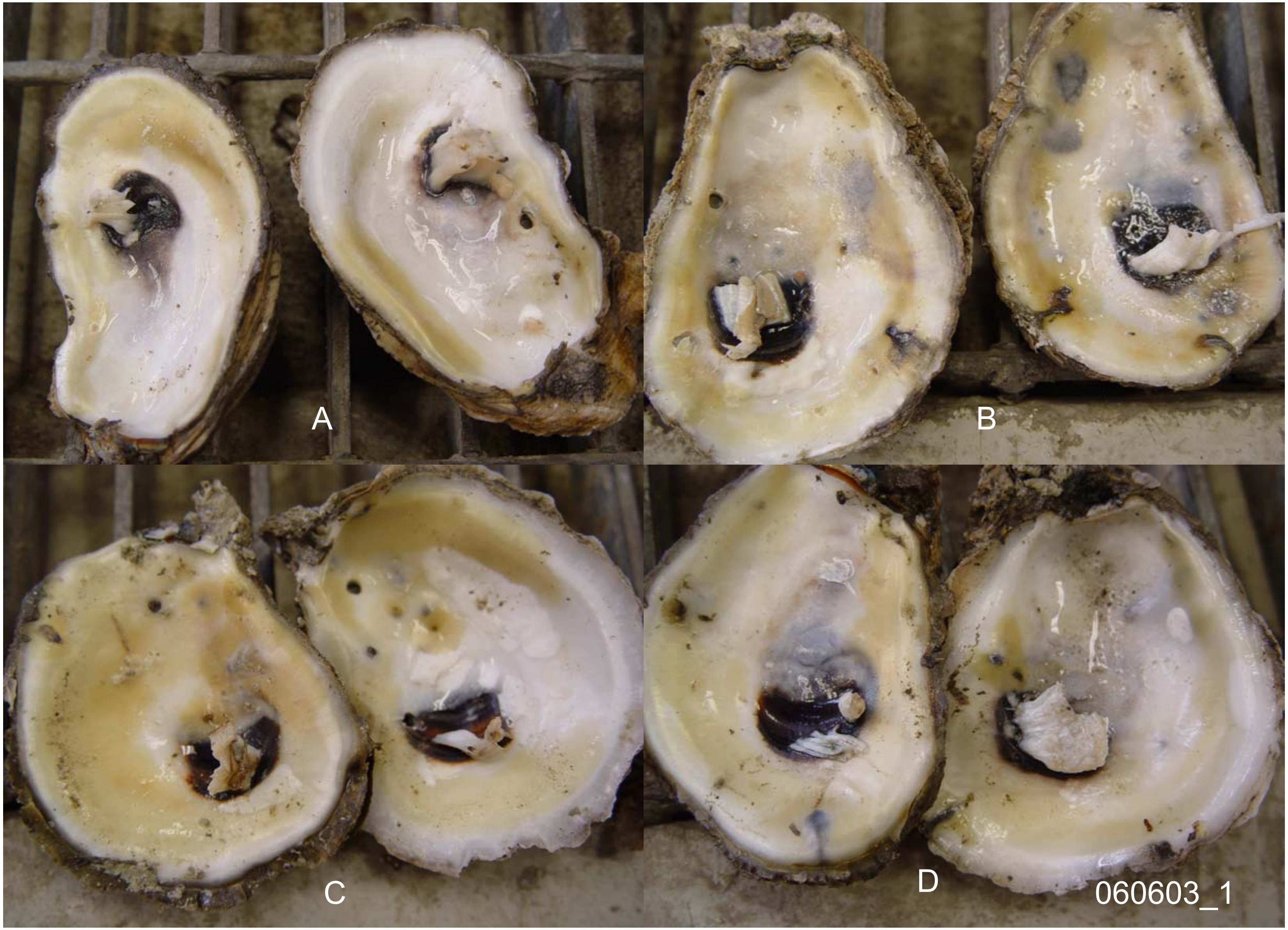

45-30-00-240 Oyster J
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
Into The Muscle
Into the Shell
Outside The Shell
071403_2

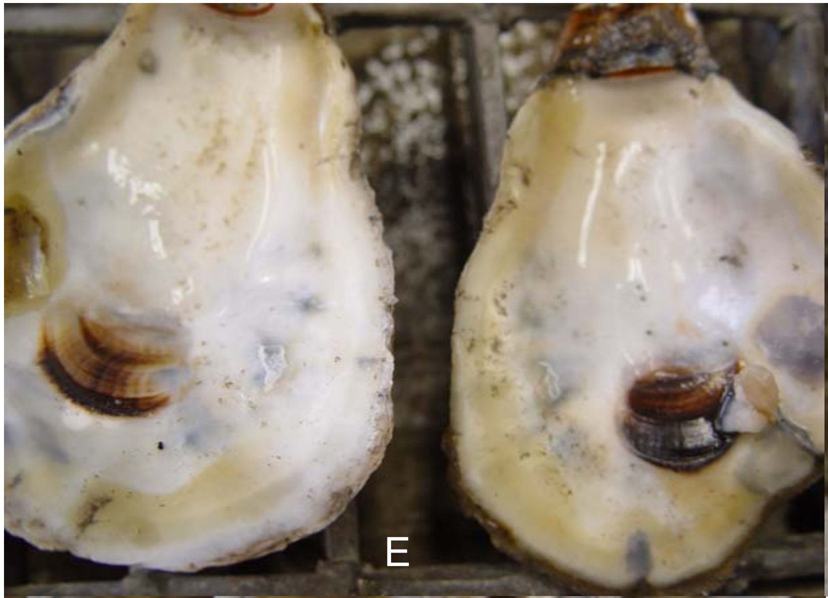

45-30-00-240 Oyster K
Into The Muscle
Into the Shell
Outside The Shell
Temperature(°C)
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
Time (s)
071403_2

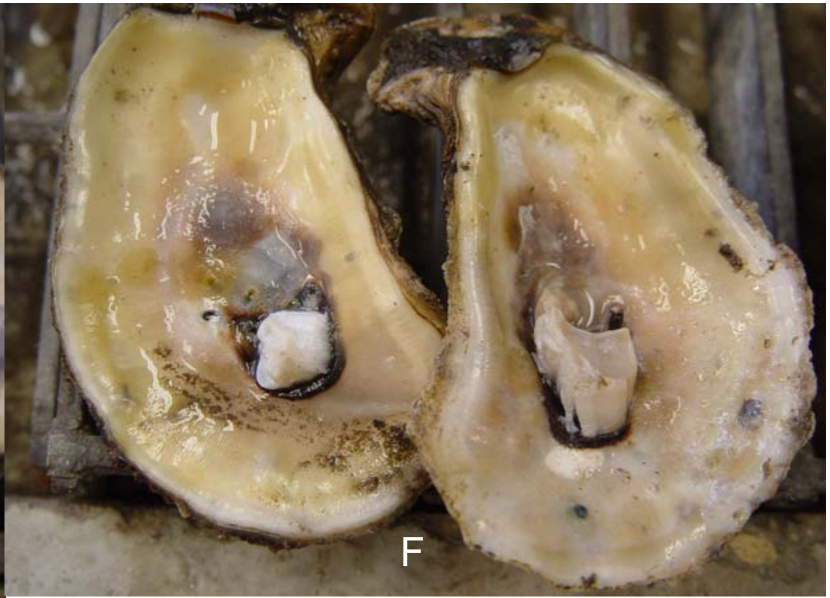
Appendix B. Oyster Photographs

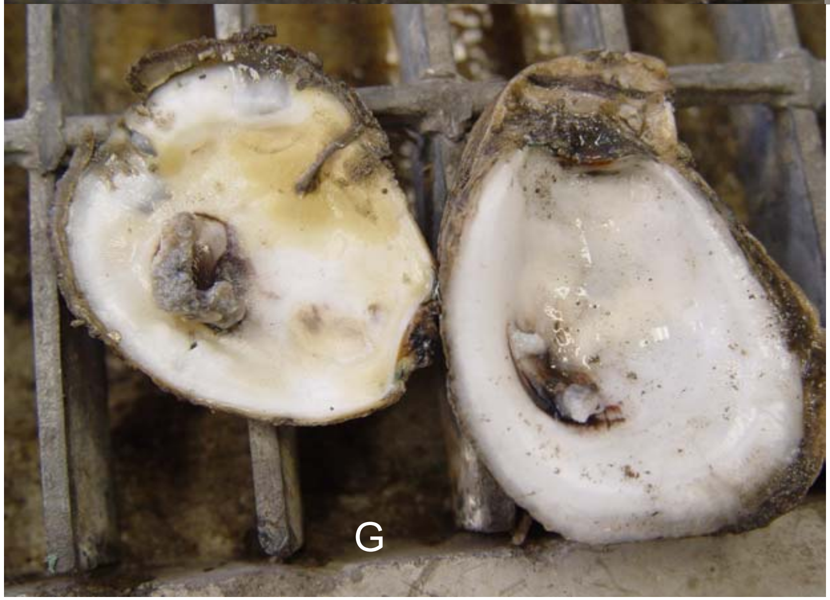
This appendix contains photos of the oysters that were subjected to thermal shucking treatments. The pictures are labeled indicating oyster number (A, B, C, etc.) and treatment which is comprised of a date stamp and run number for the day.

These pictures are useful for documenting and examining the overall shape and condition of the shells after treatment. In addition, they reveal the amount and type of muscle still attached to the shells after treatment. It would be difficult to determine actual size of the shells from the pictures since the photographs were taken so that the shells would fill the frame and not from the same distance away each time. The shell dimensions, however, were measured and are recorded in the data sheets in Appendix C.

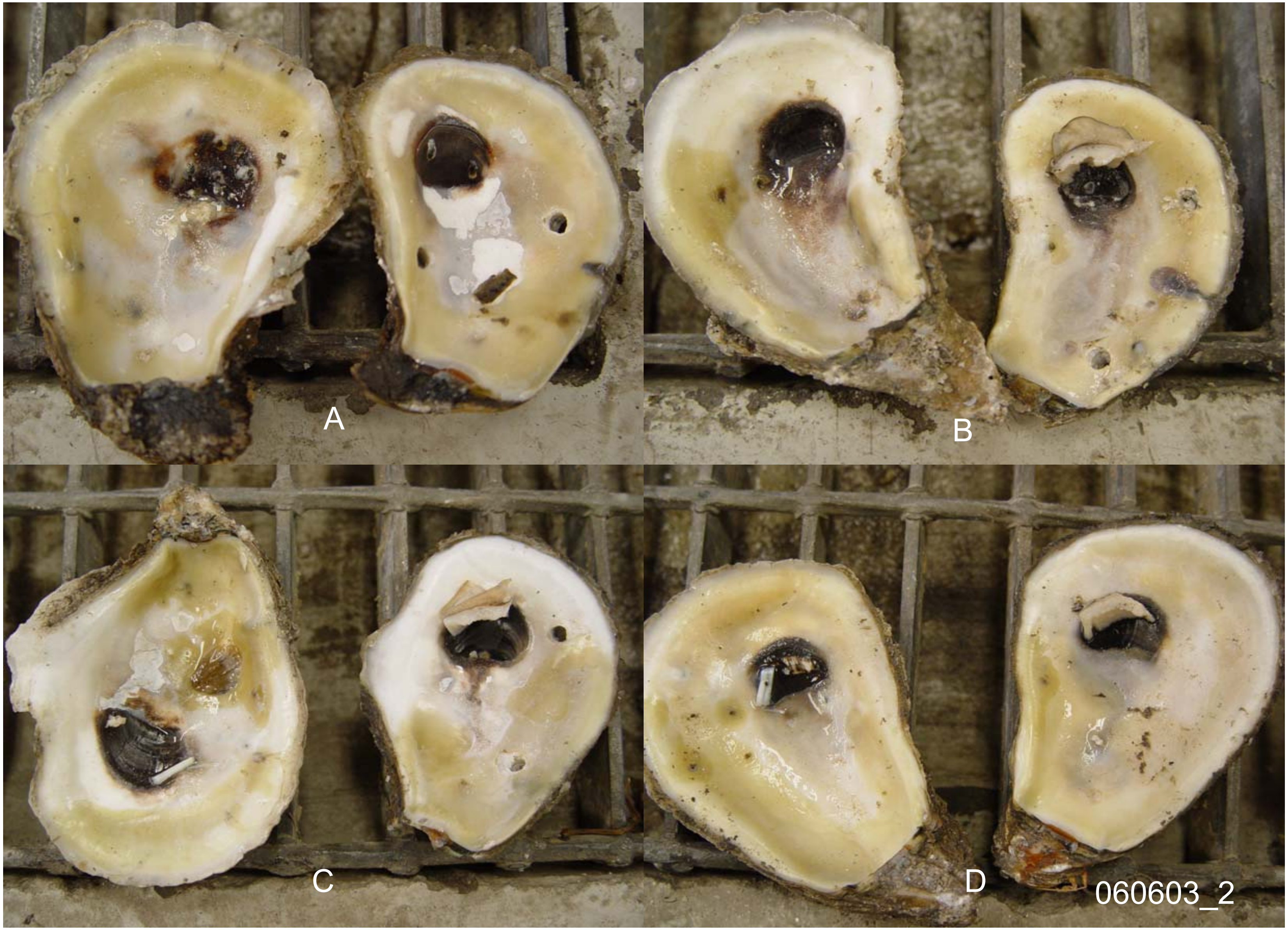

A
B
C
D
060603_1

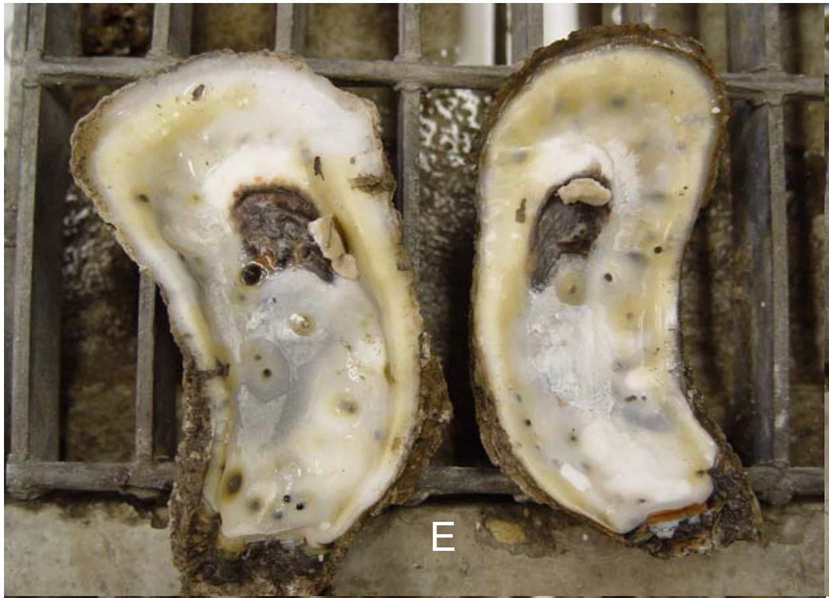


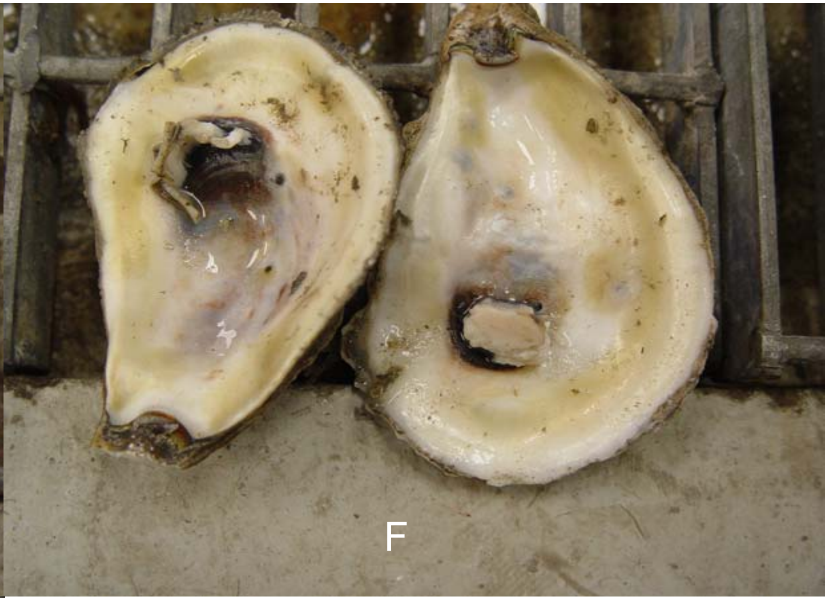




060603_1


A
B
C
D
060603_2


E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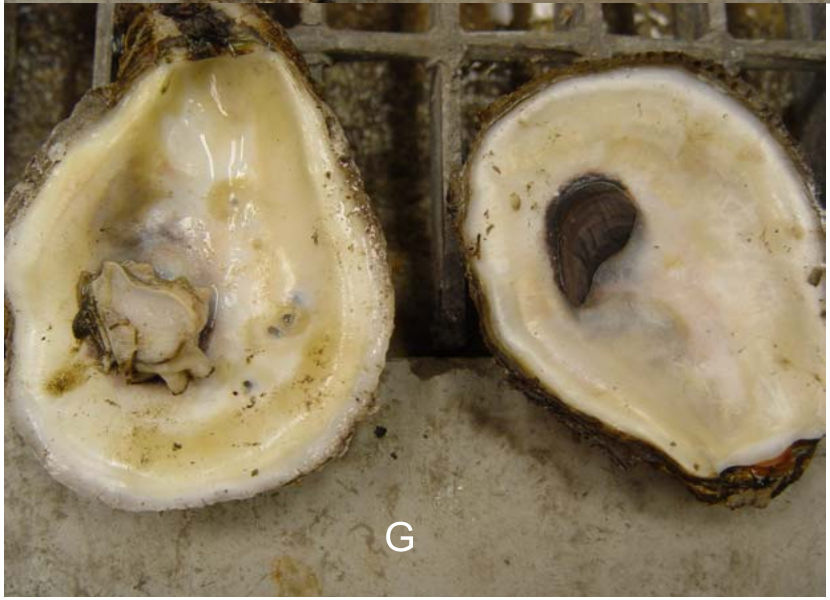
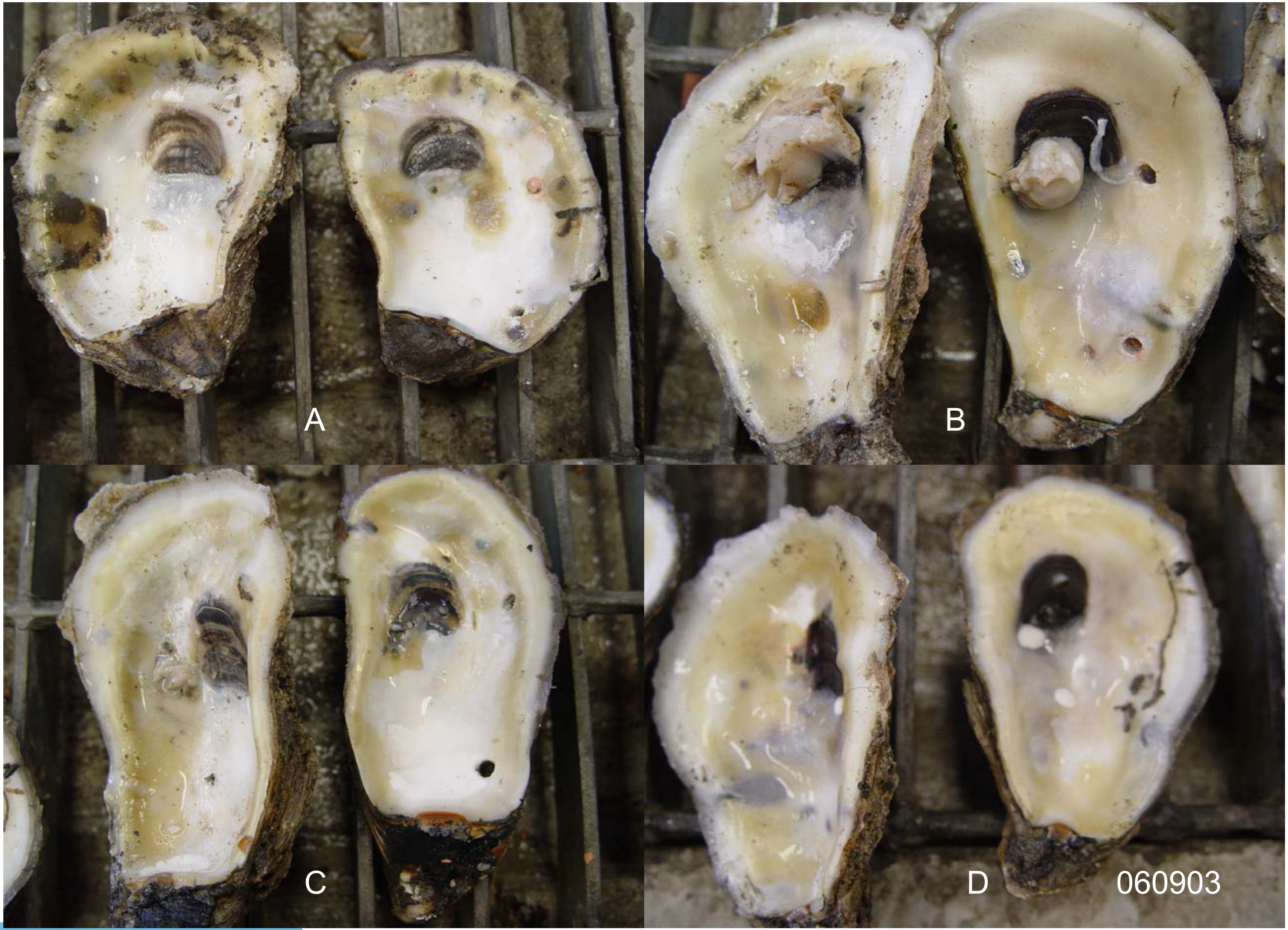
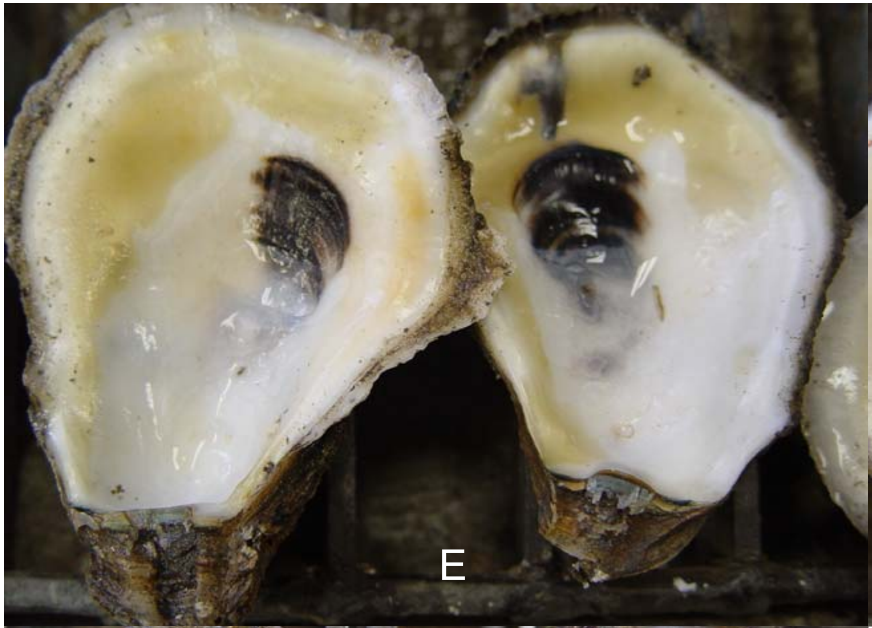

G

060603_2


A
B
C
D
060903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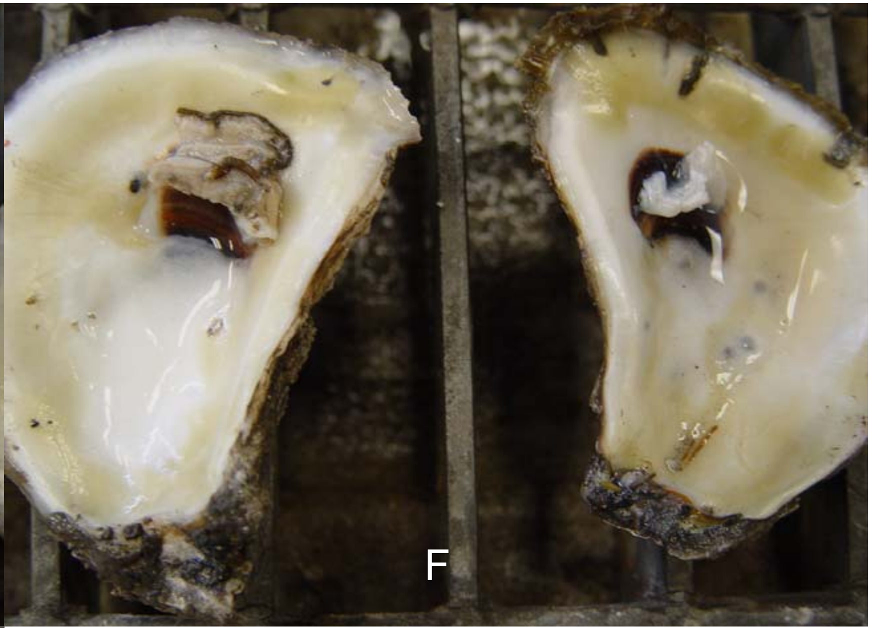
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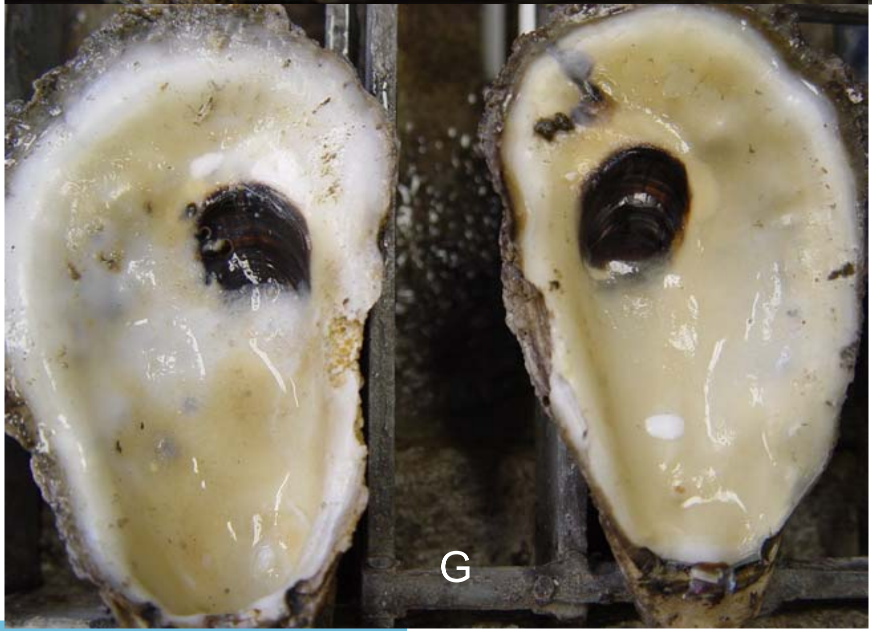
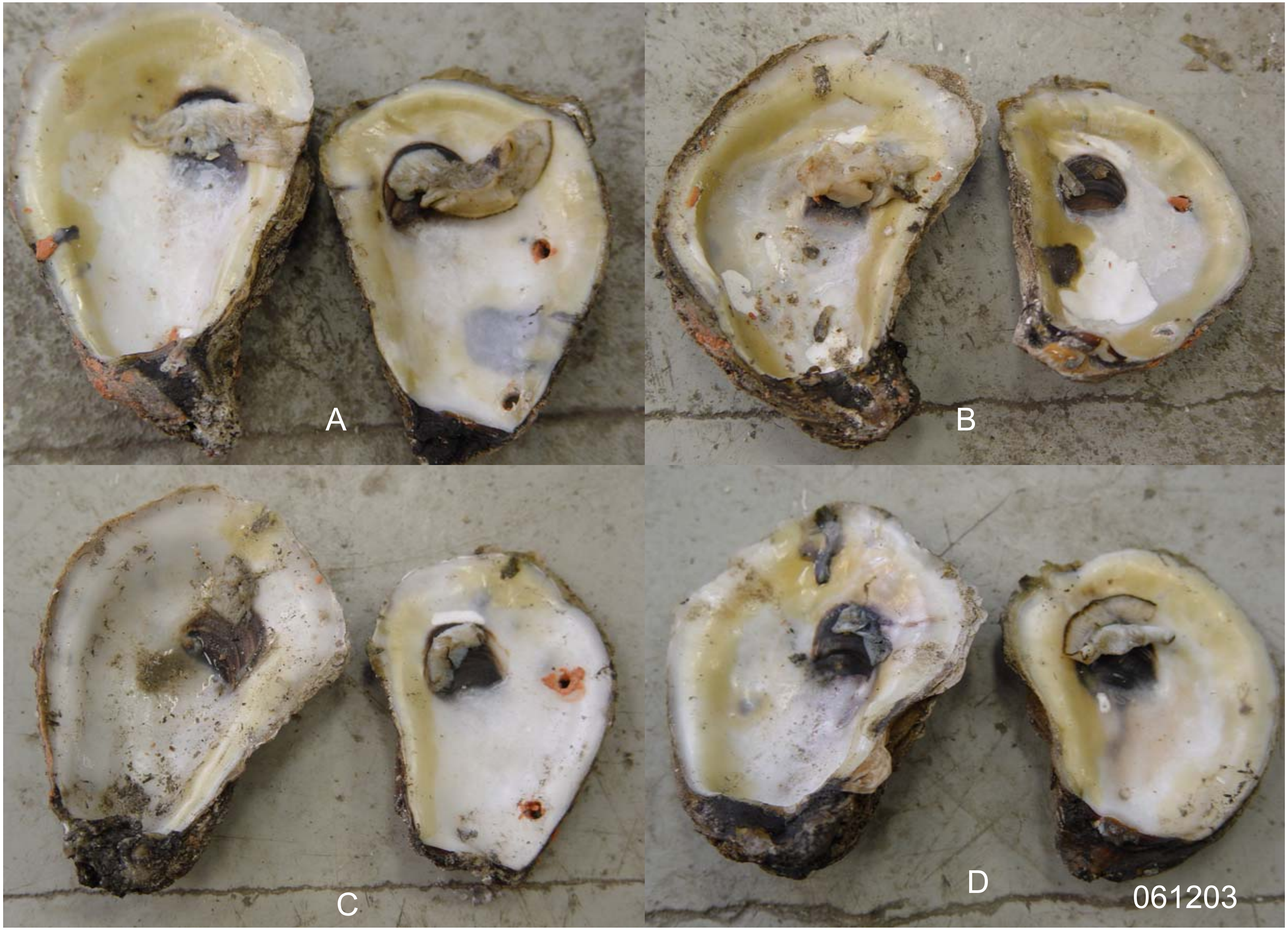
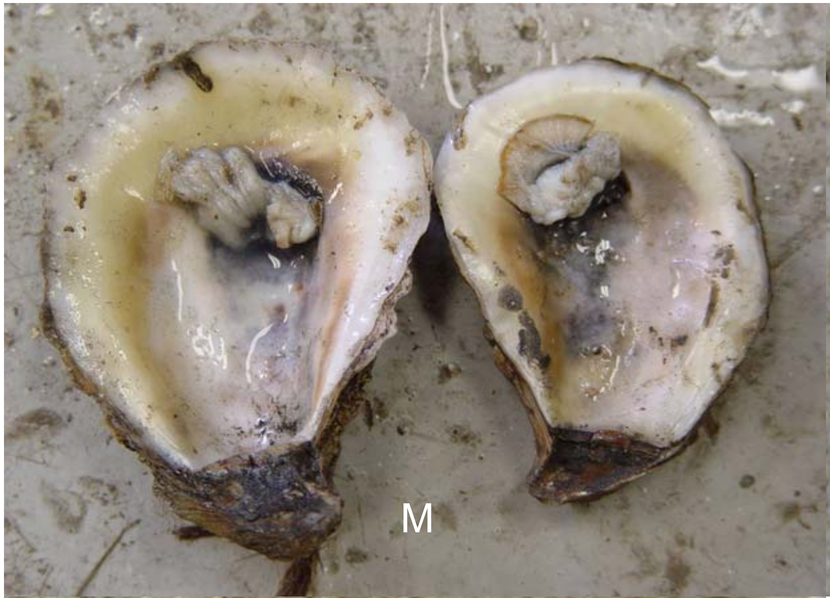

G

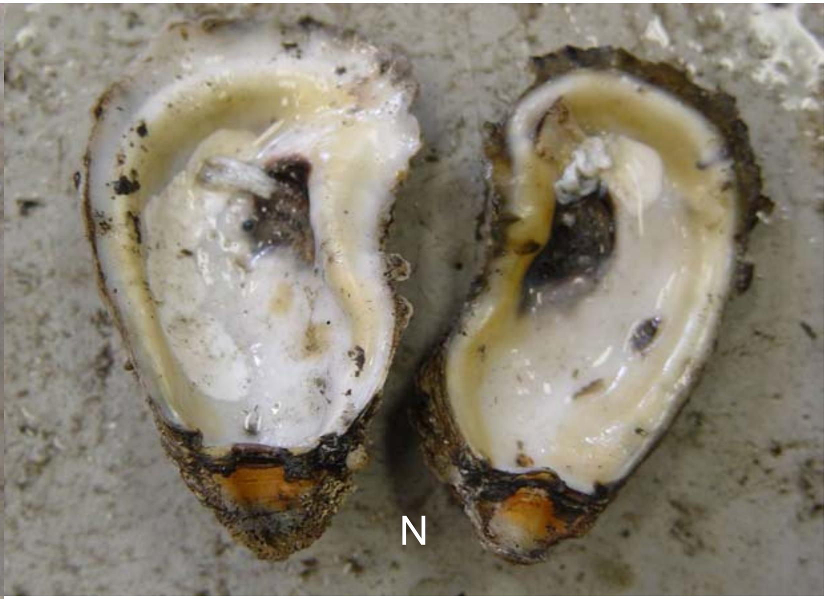
060903


A
B
C
D
061203

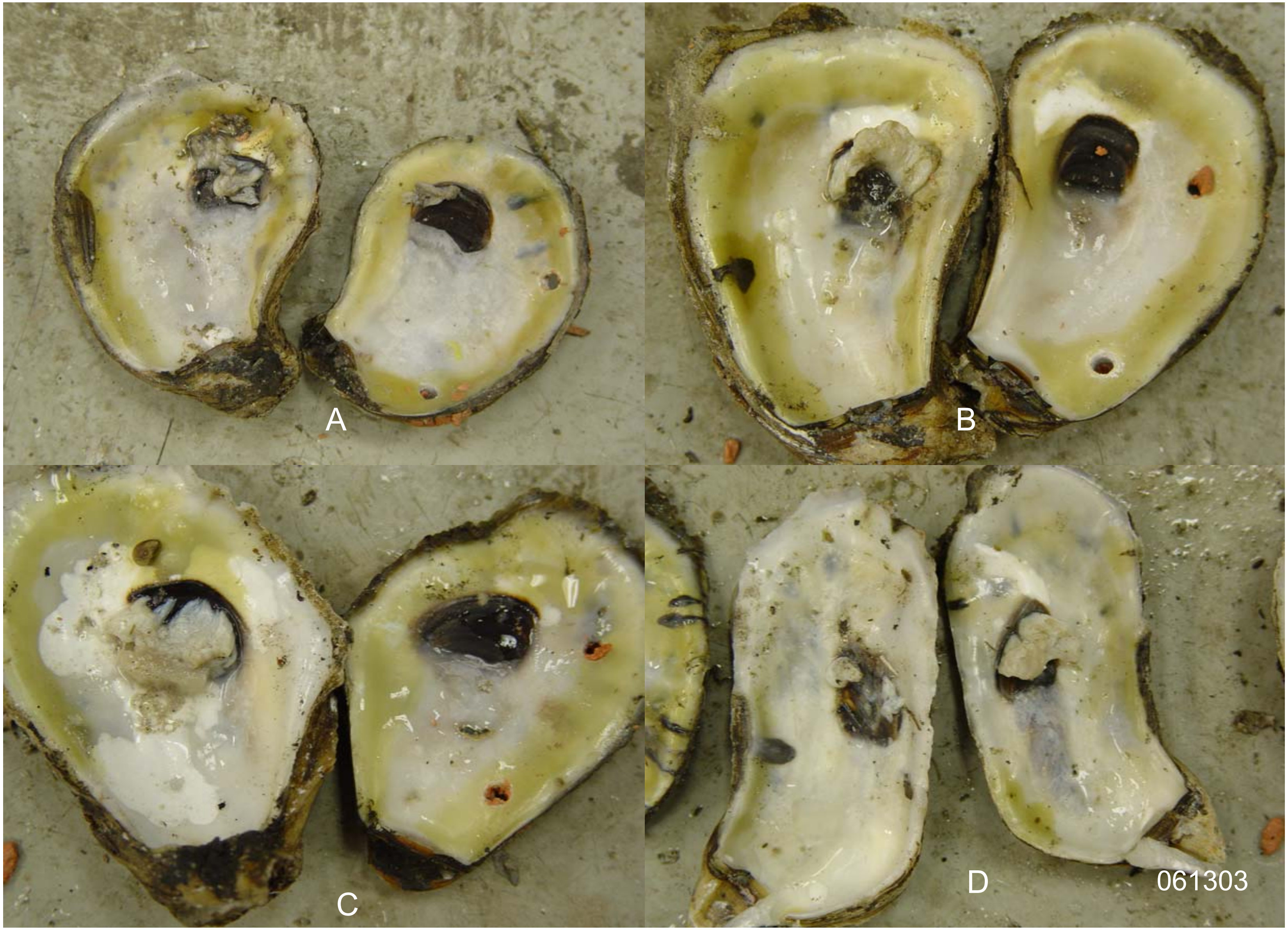

E
F
G
H
061203


I
J
K
L
061203



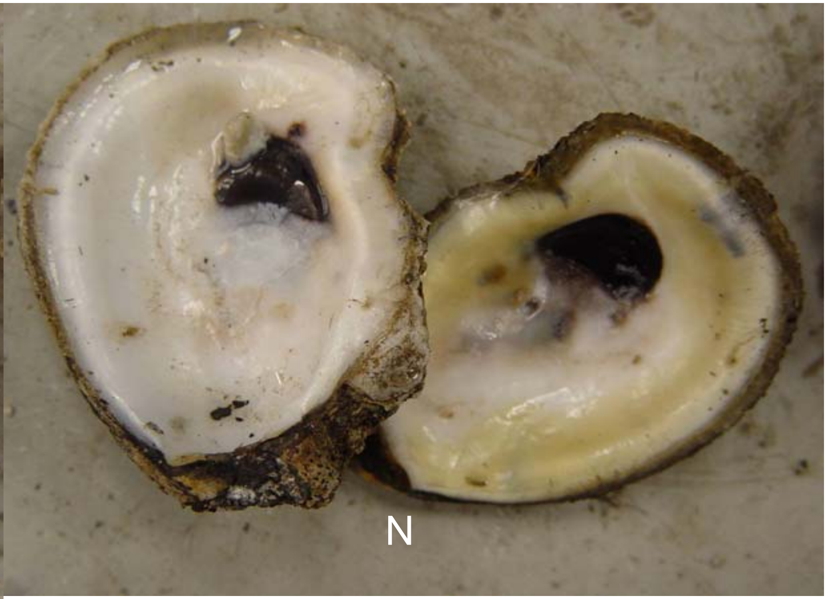


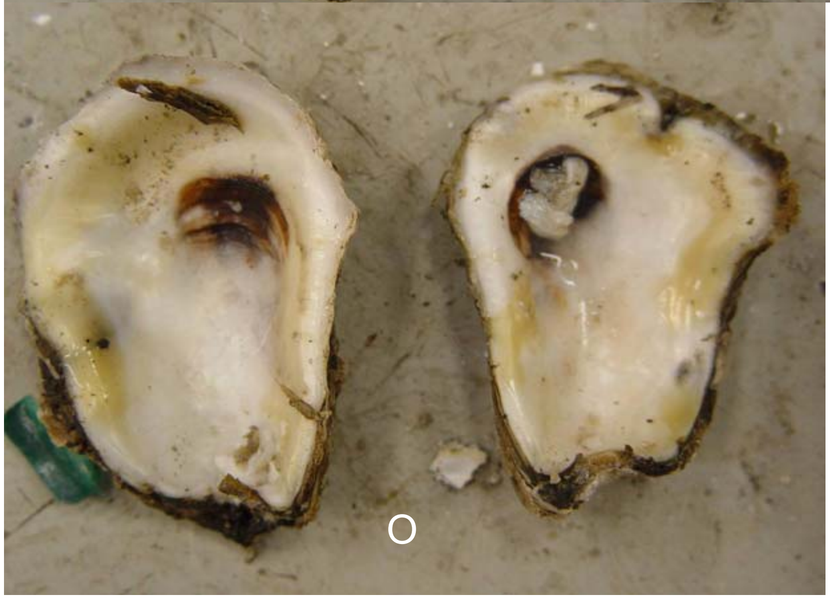
061203


A
B
C
D
061303


E
F
G
H
061303

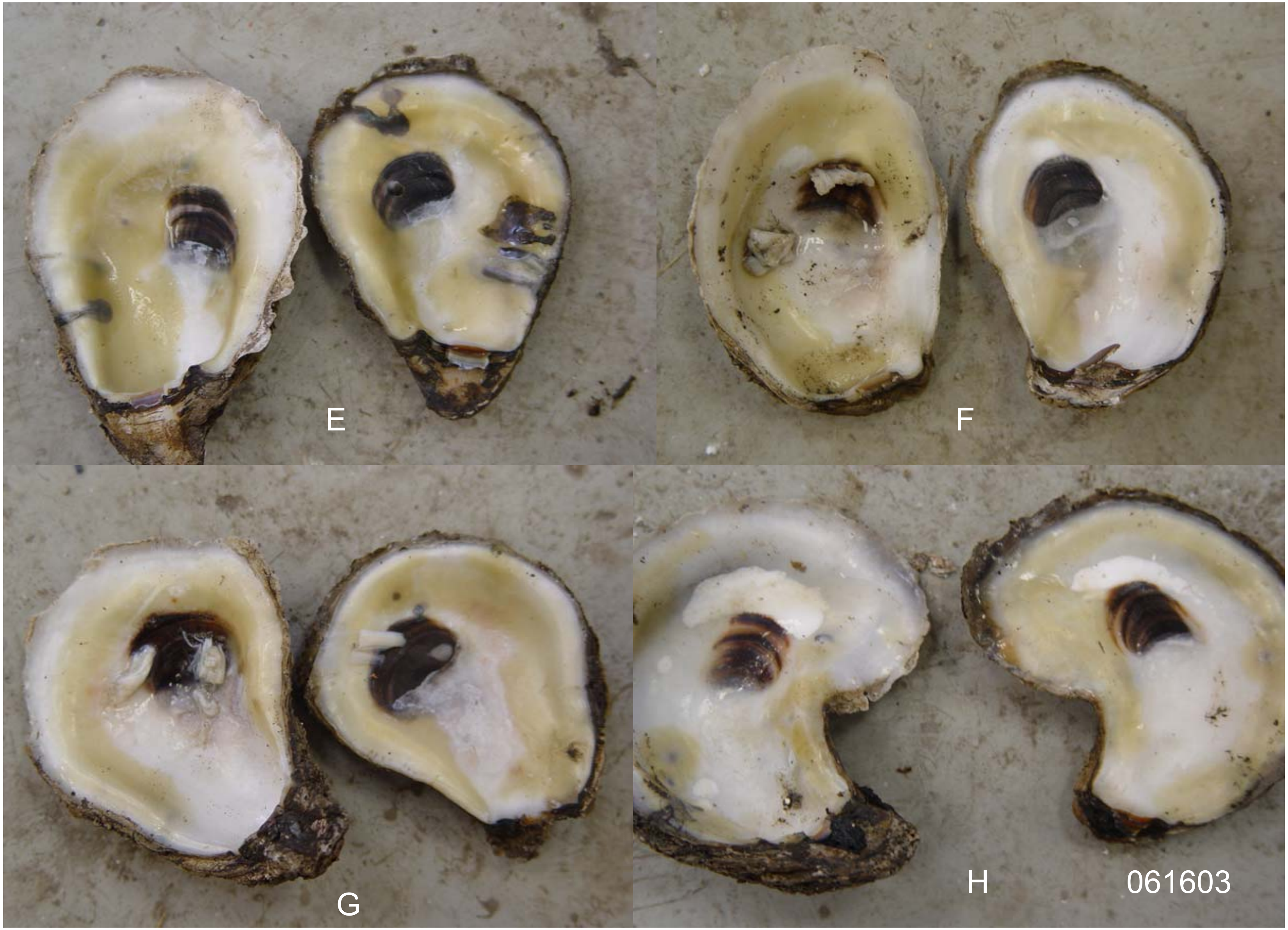

I
J
K
L
061303

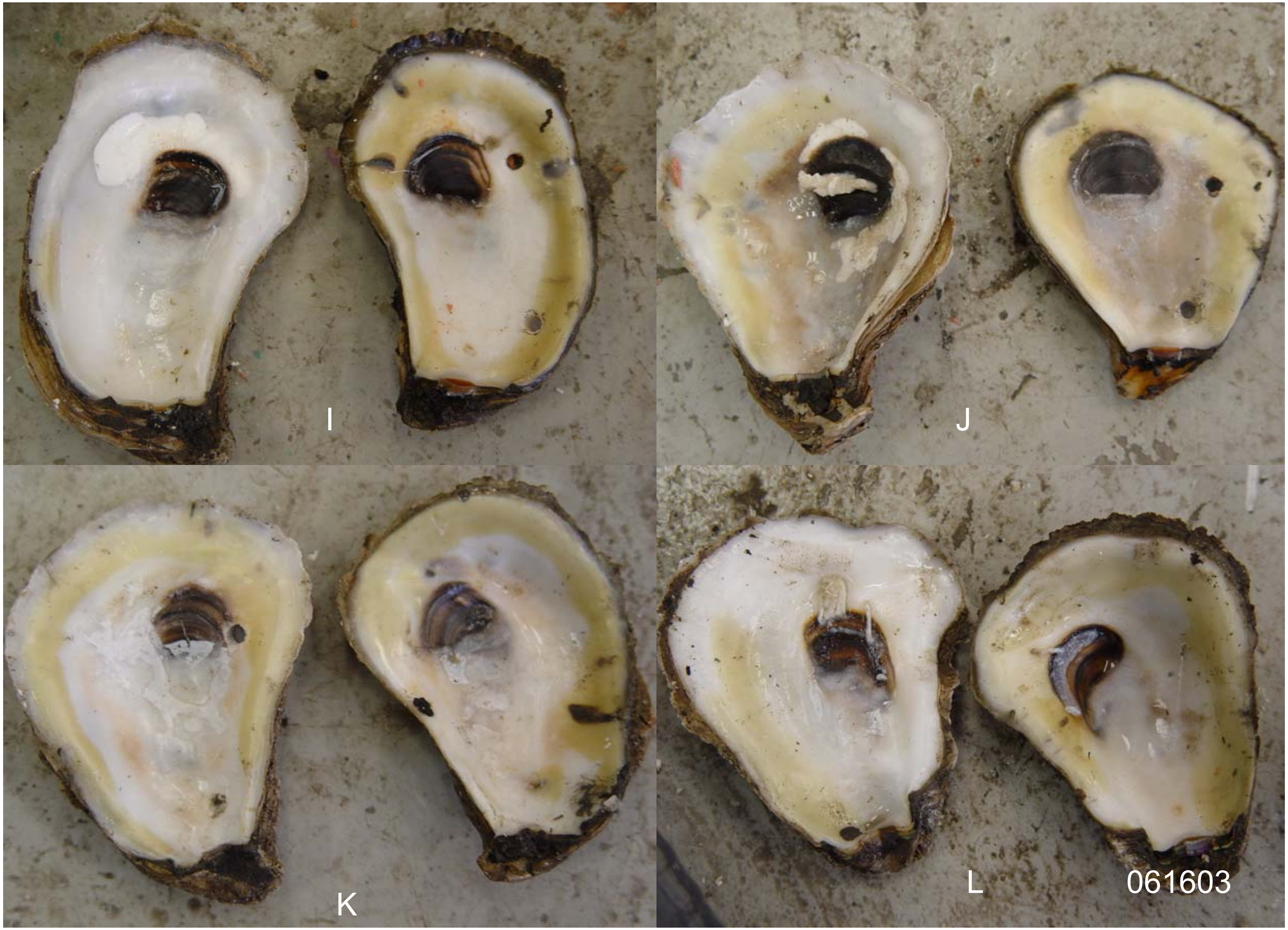


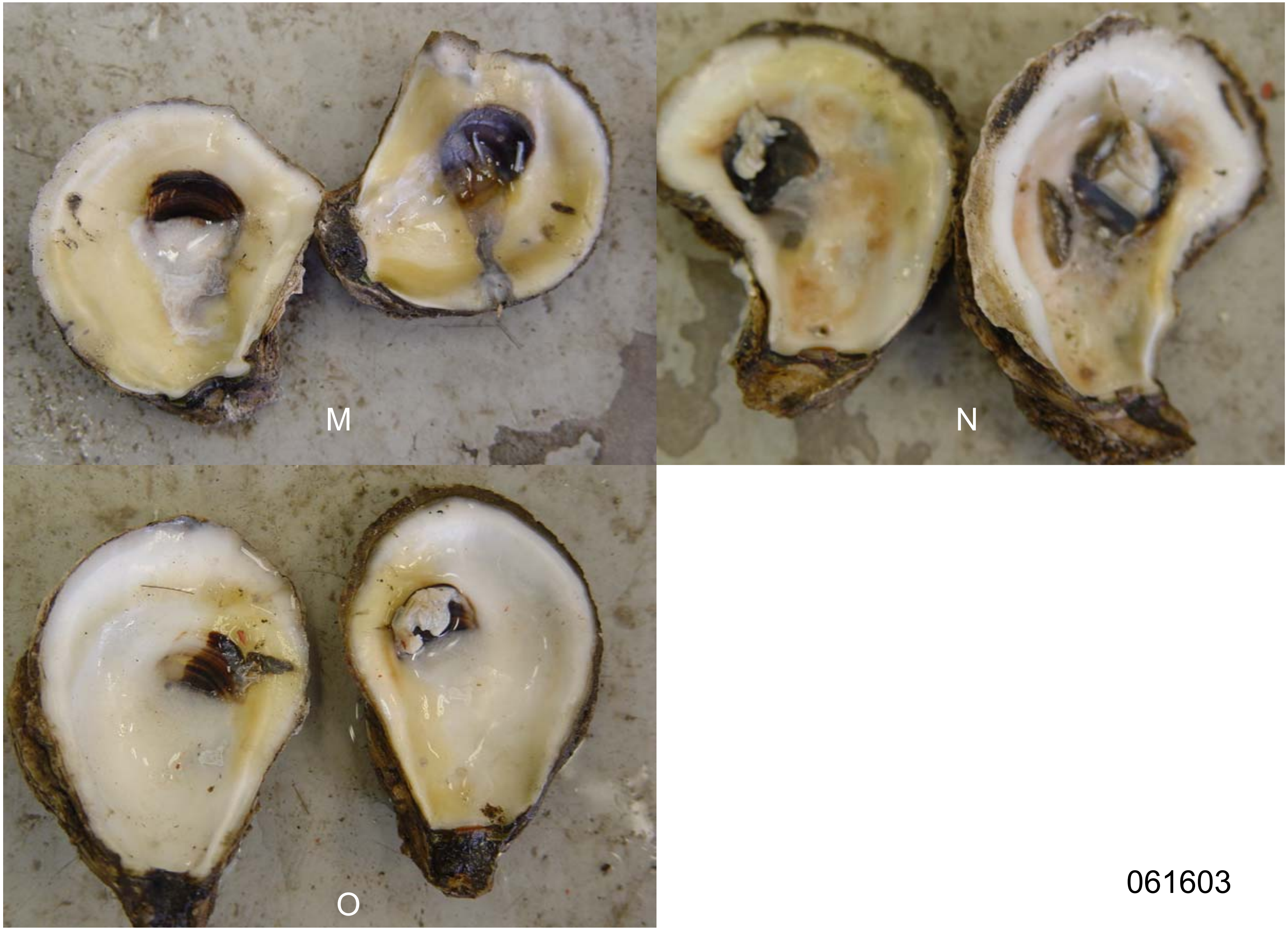


061303


A
B
C
D
061603

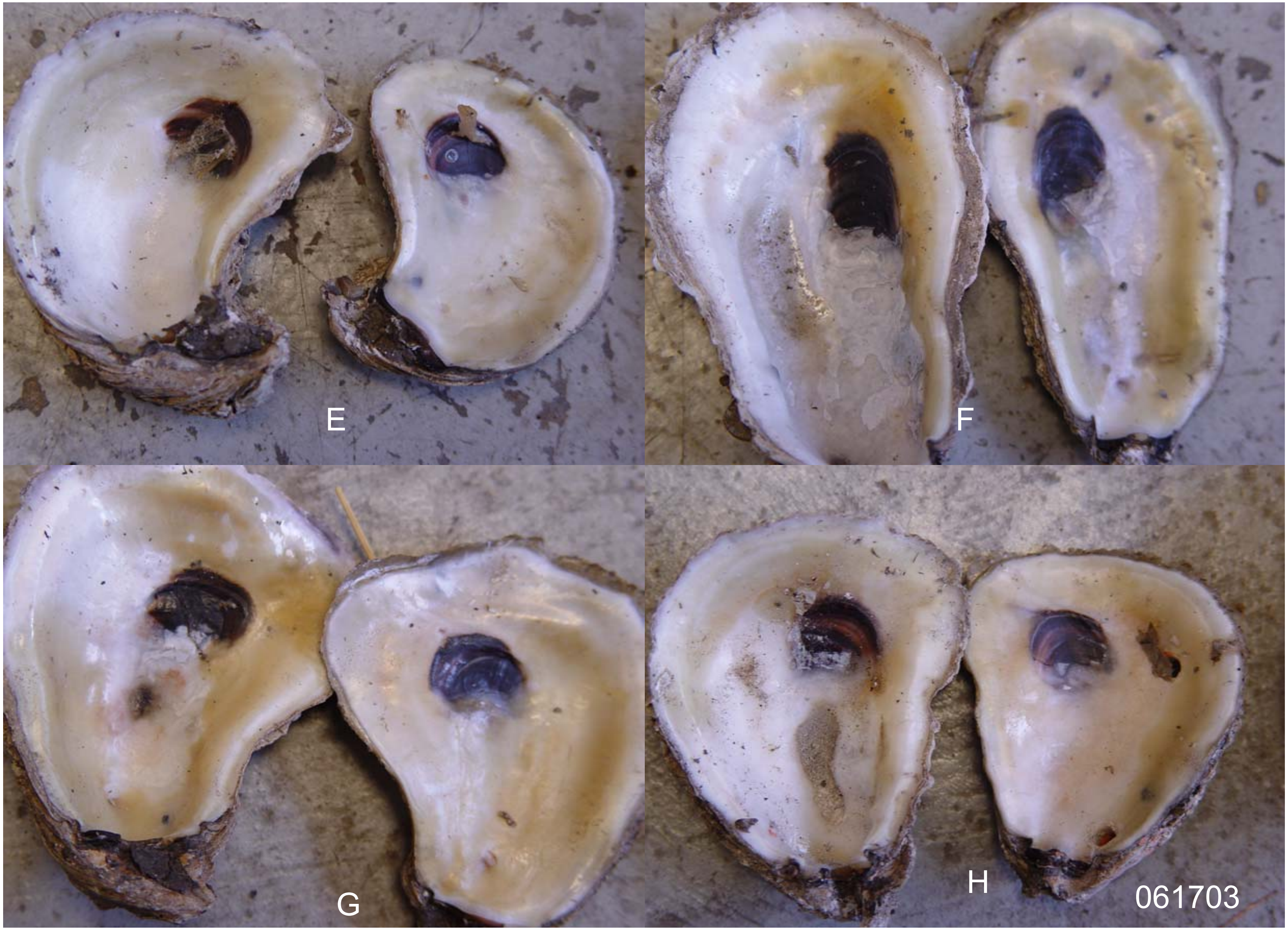

E
F
G
H
061603


I
J
K
L
061603

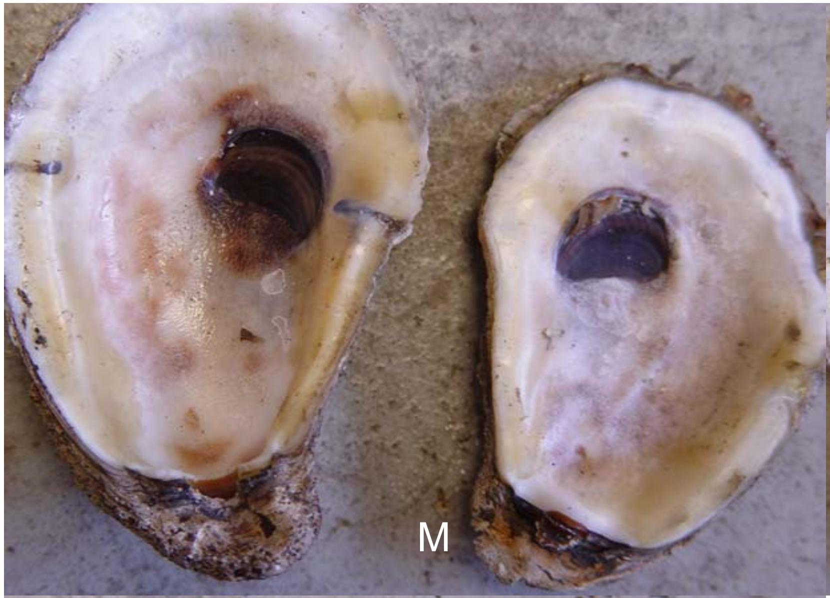


061603

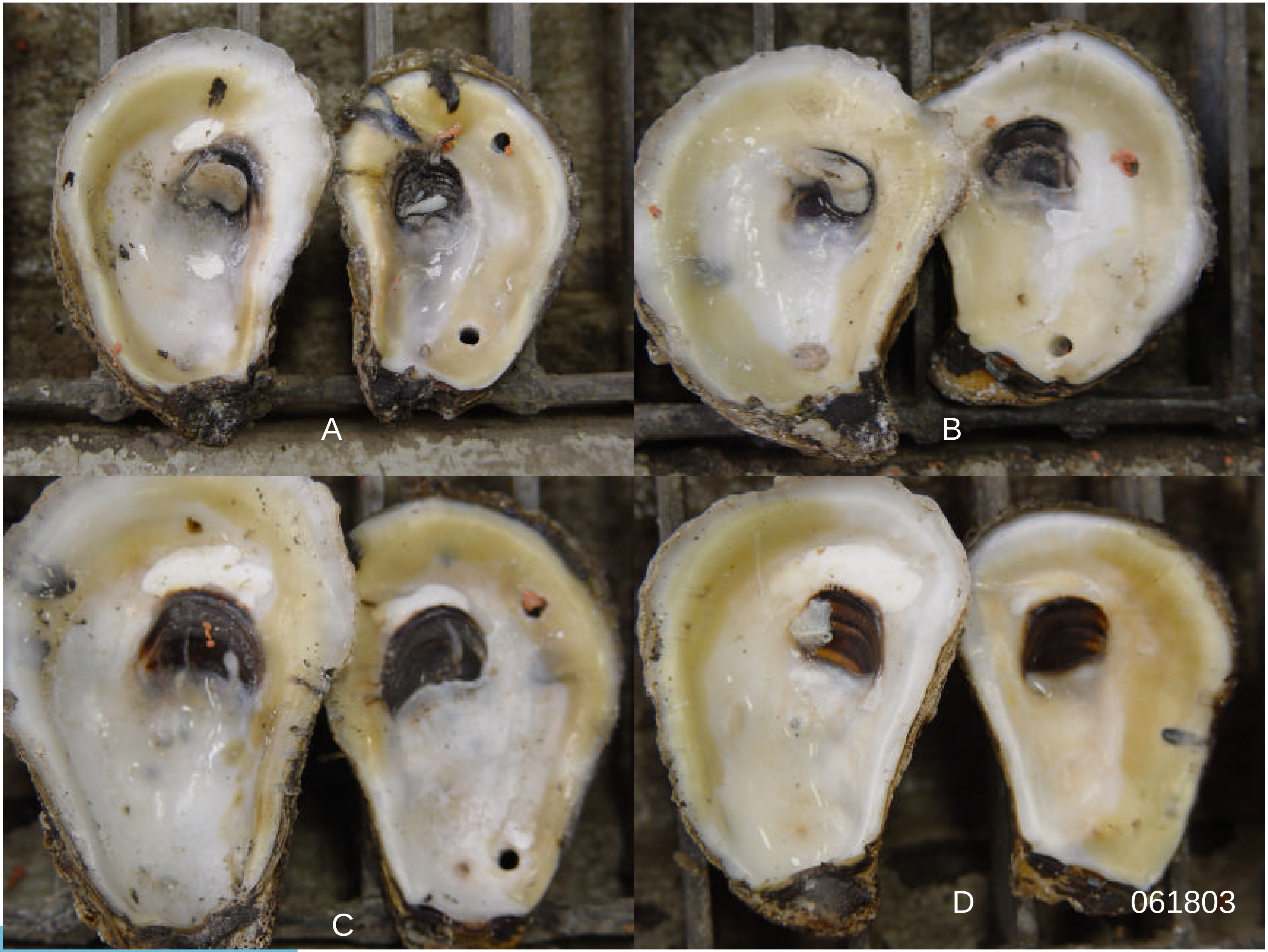

A
B
C
D
061703


E
F
G
H
061703

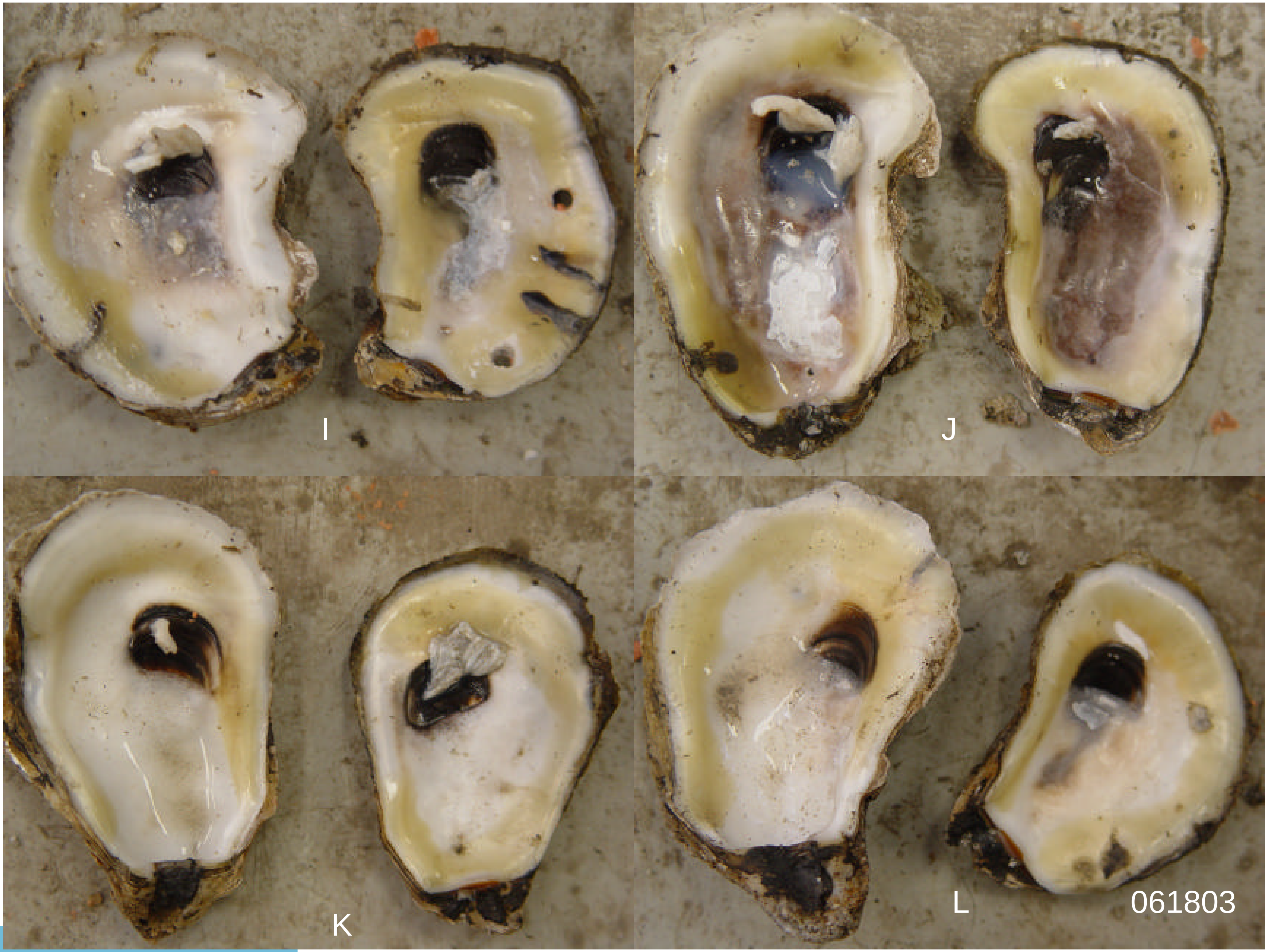

I
J
K
L
061703

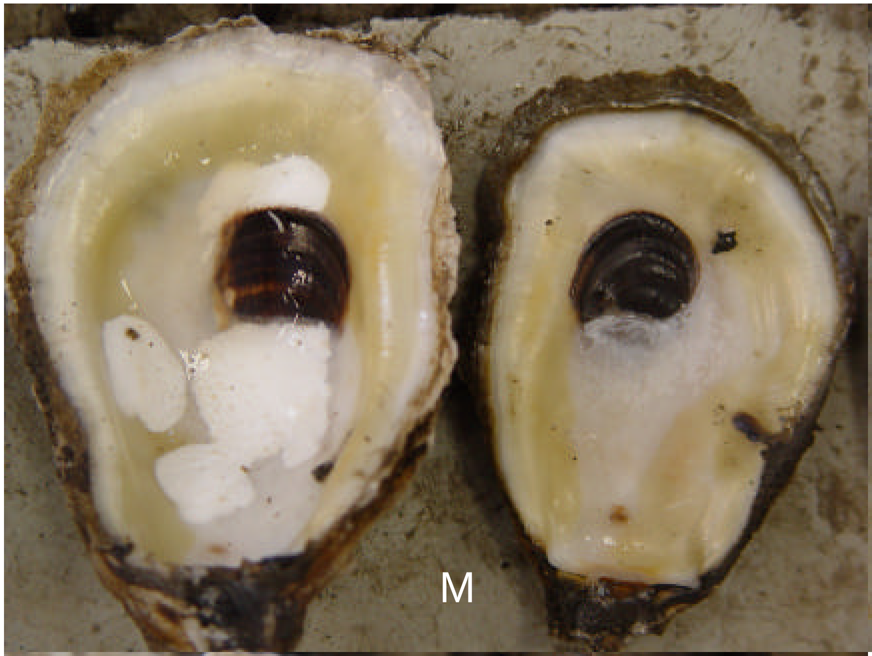


061703

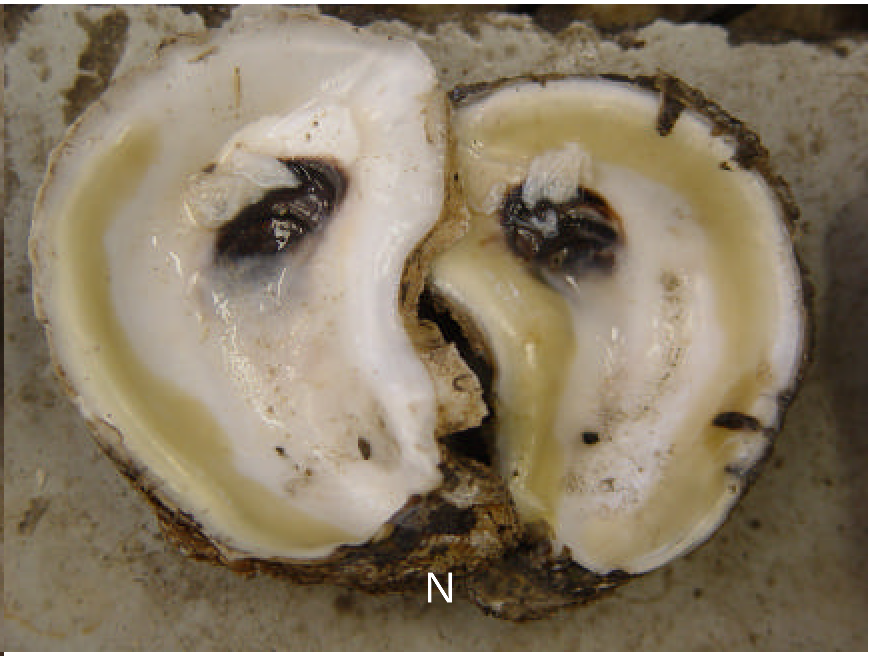

A
B
C
D
061803


E
F
G
H
061803

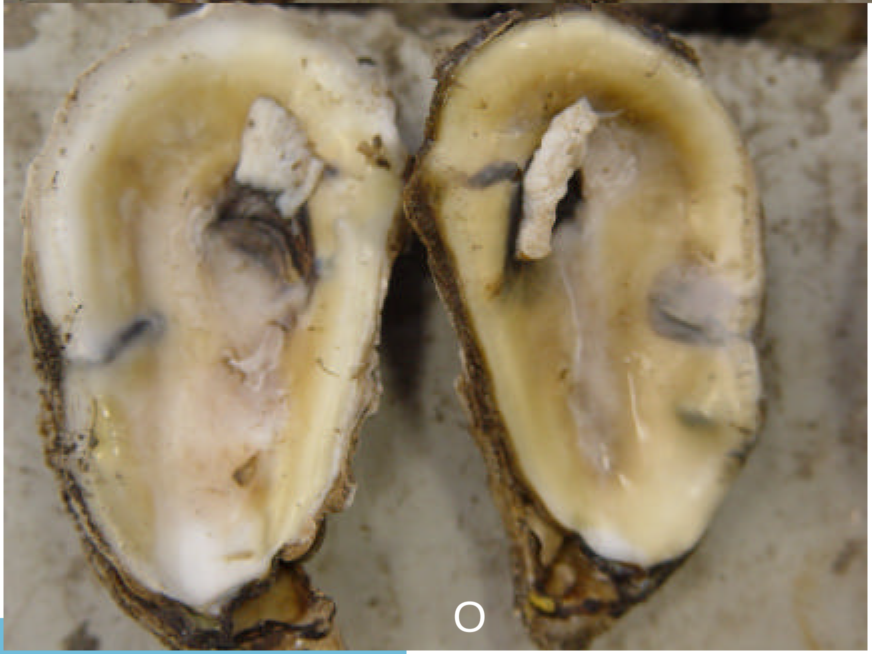

I
J
K
L
061803



M



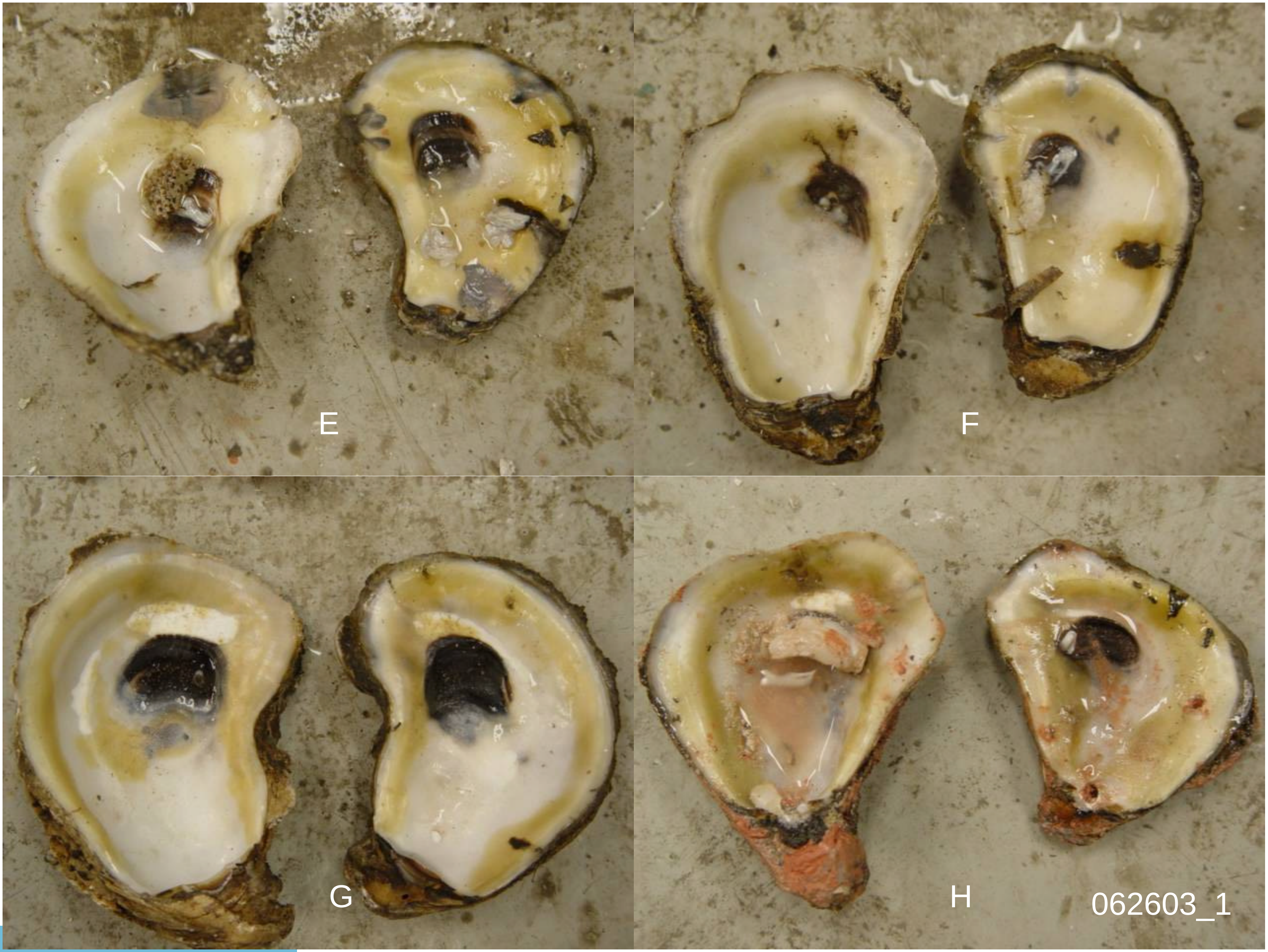
N



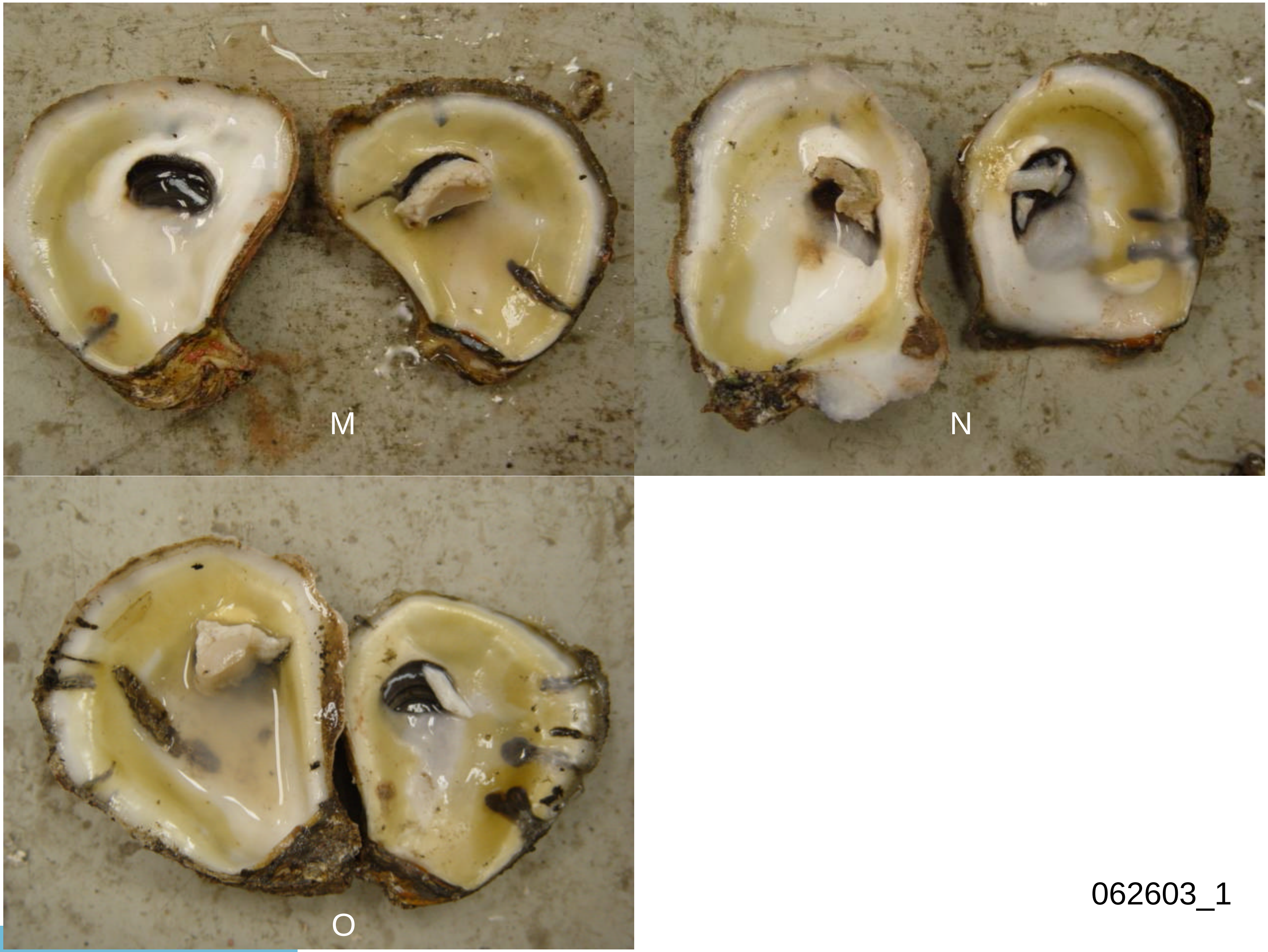
O

061803

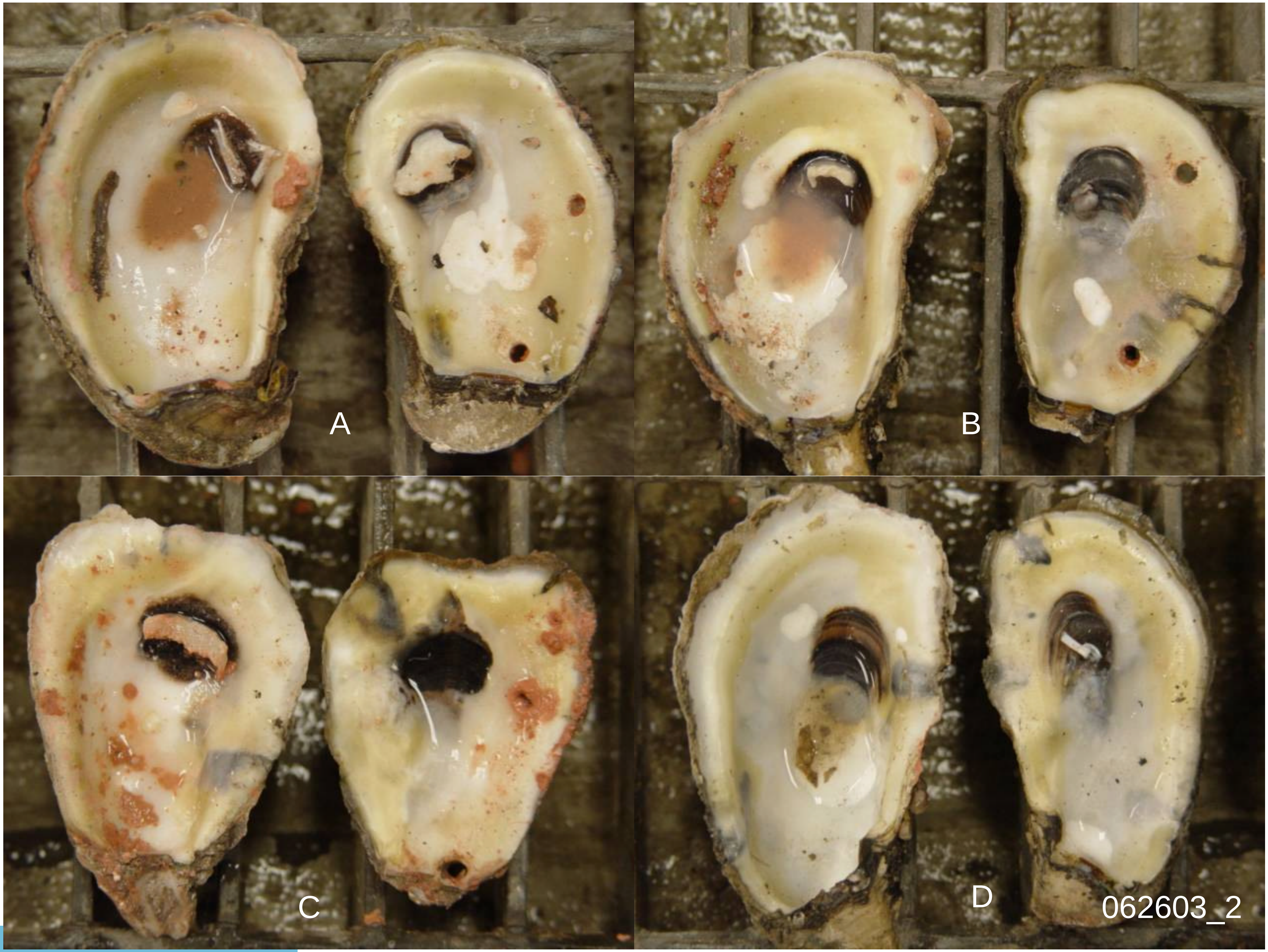

A
B
C
D
062603_1

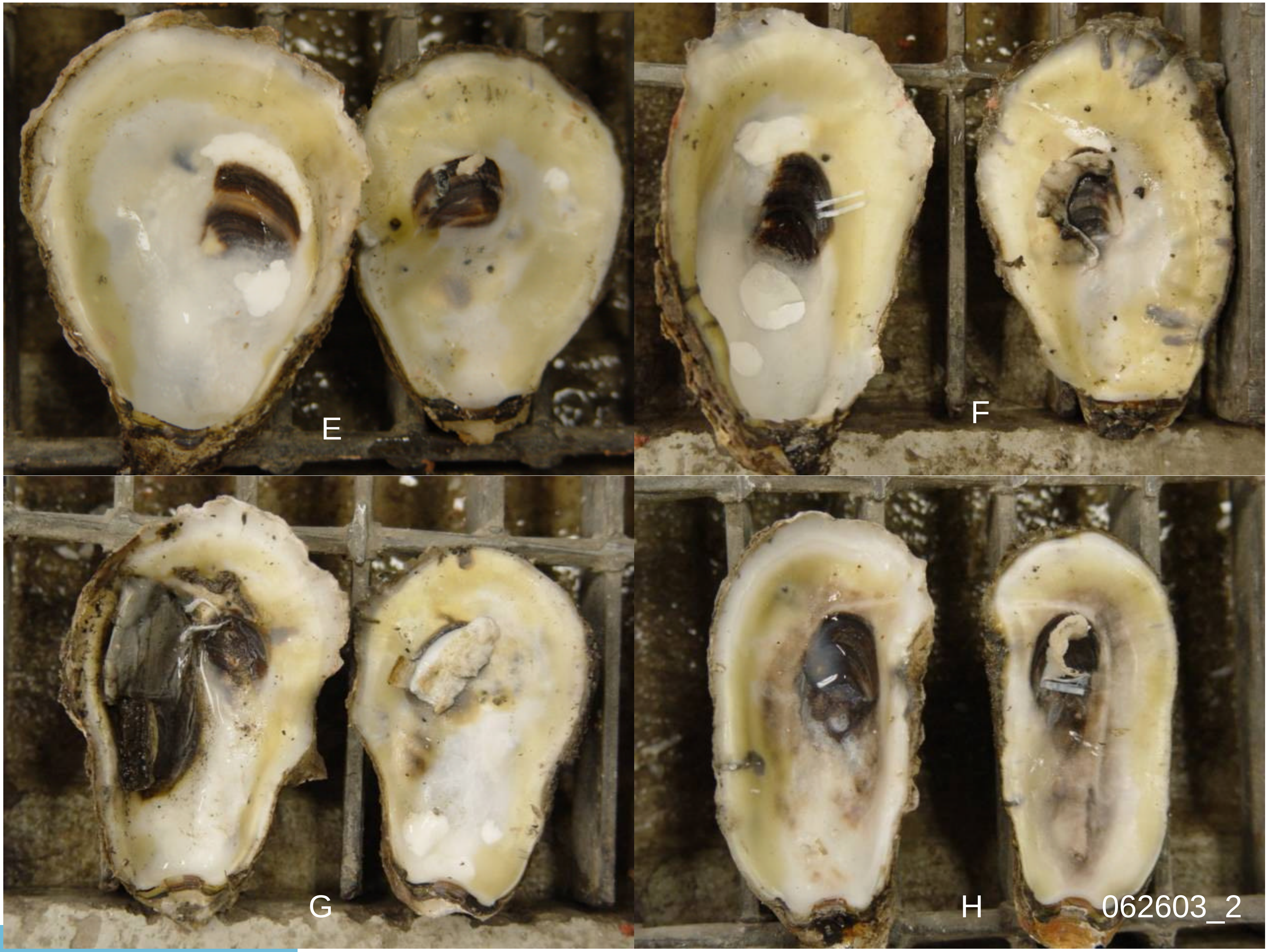

E
F
G
H
062603_1

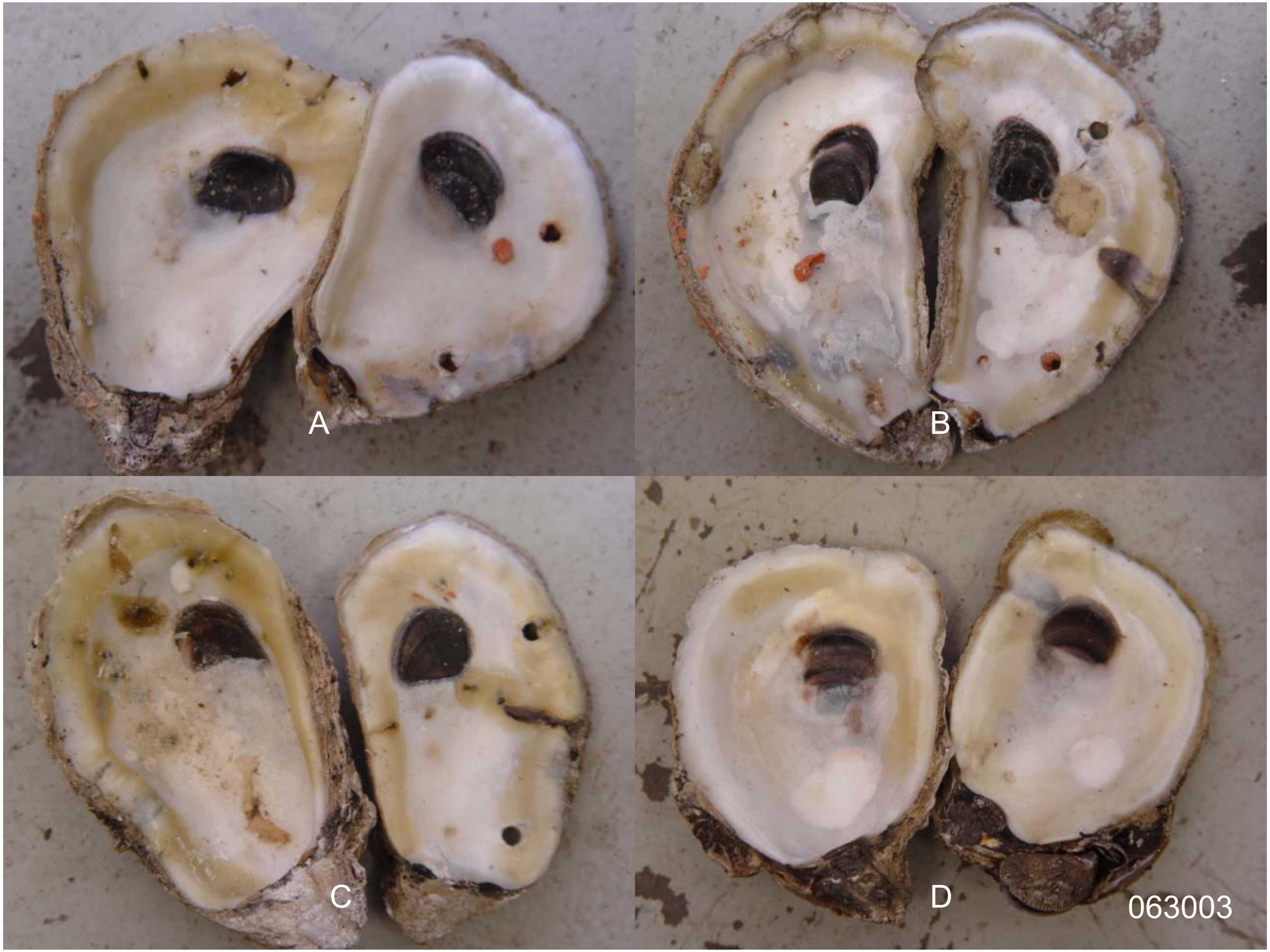

I
J
K
L
062603_1



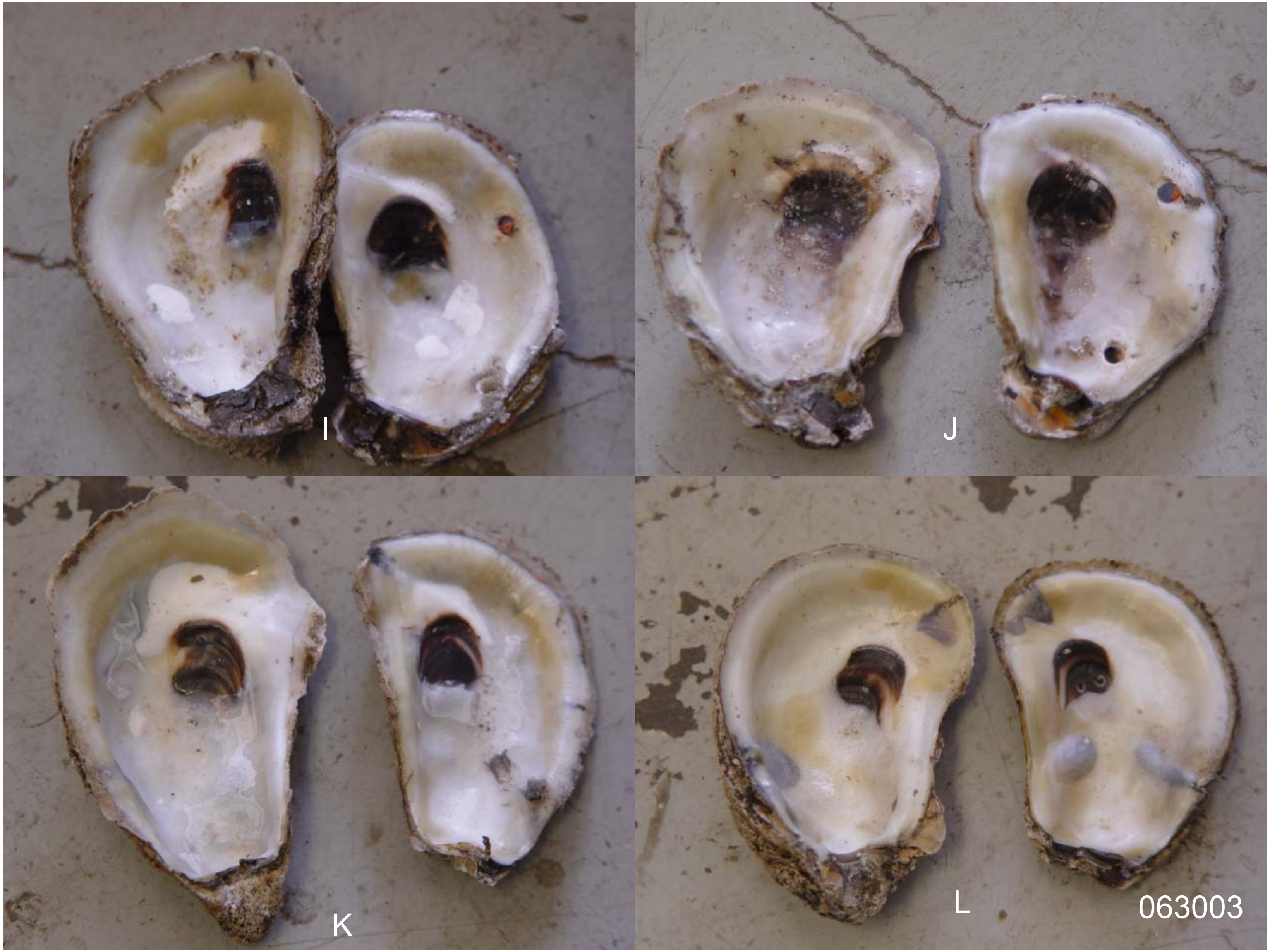
062603_1


A
B
C
D
062603_2

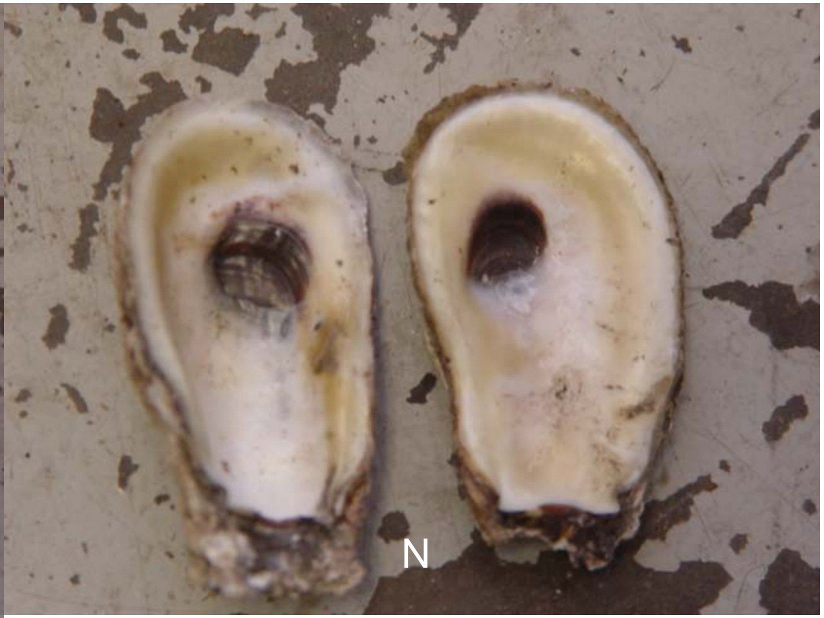

E
F
G
H
062603_2


A
B
C
D
063003


E
F
I
H
063003

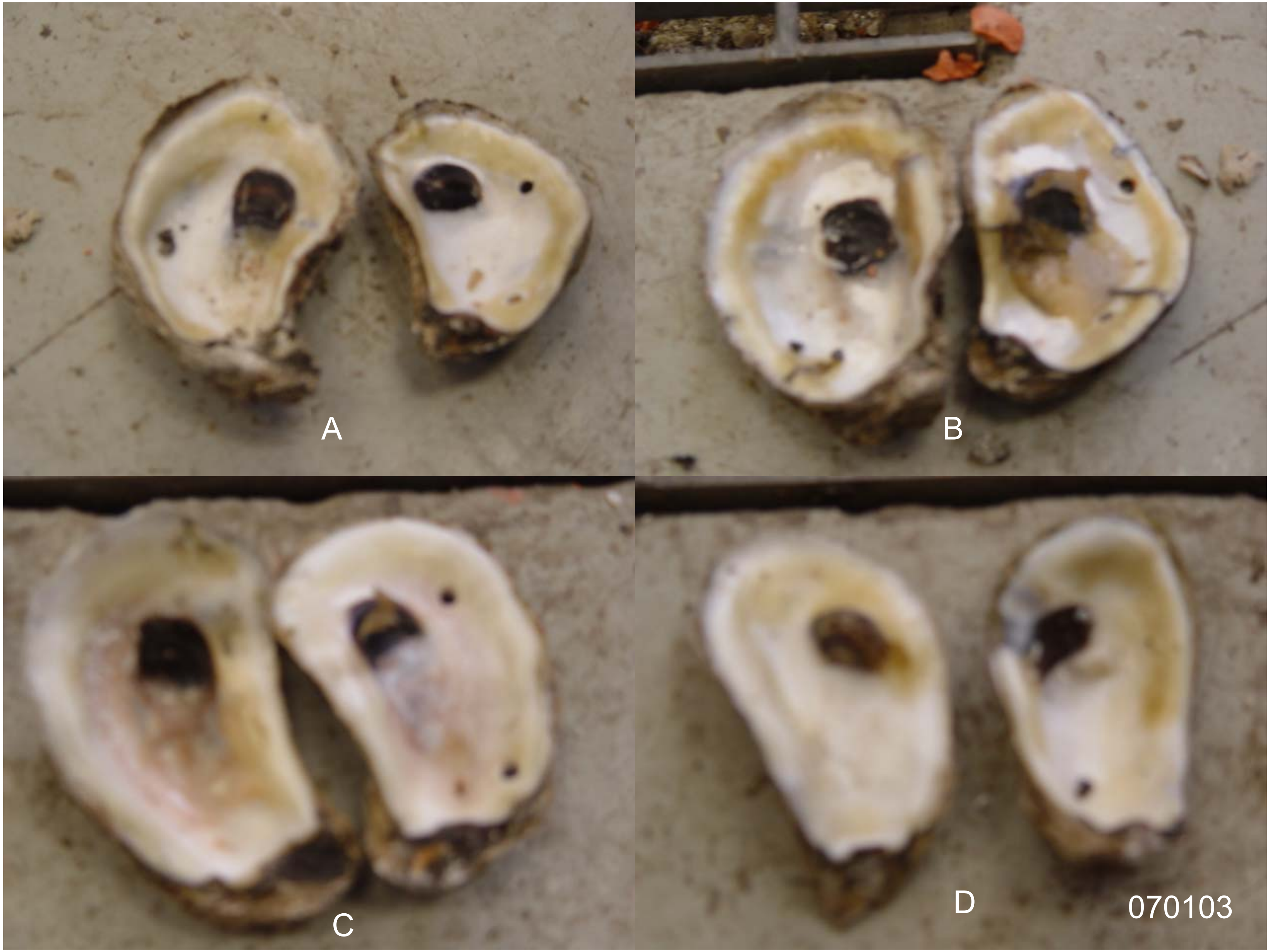

I
J
K
L
063003

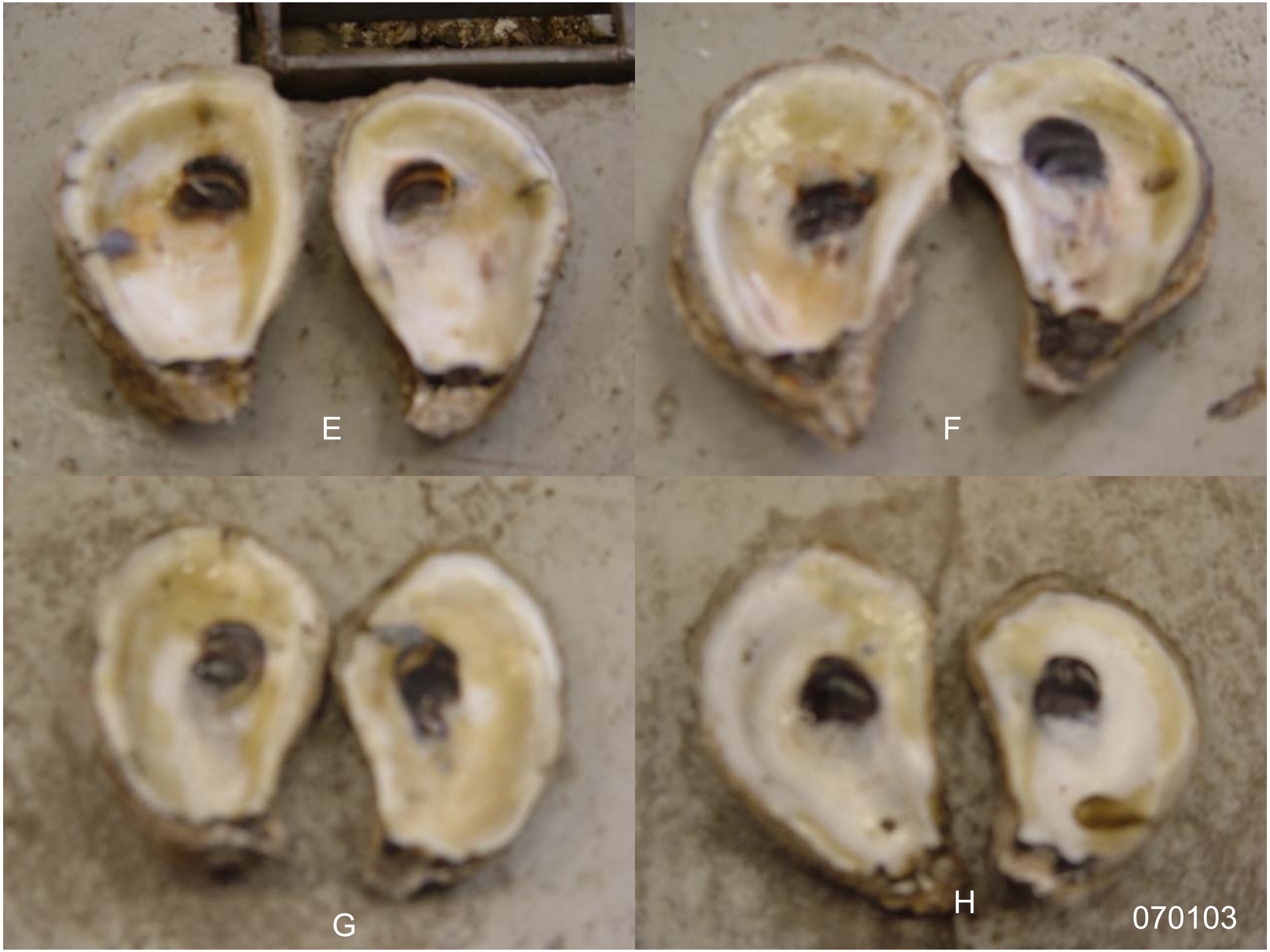

M

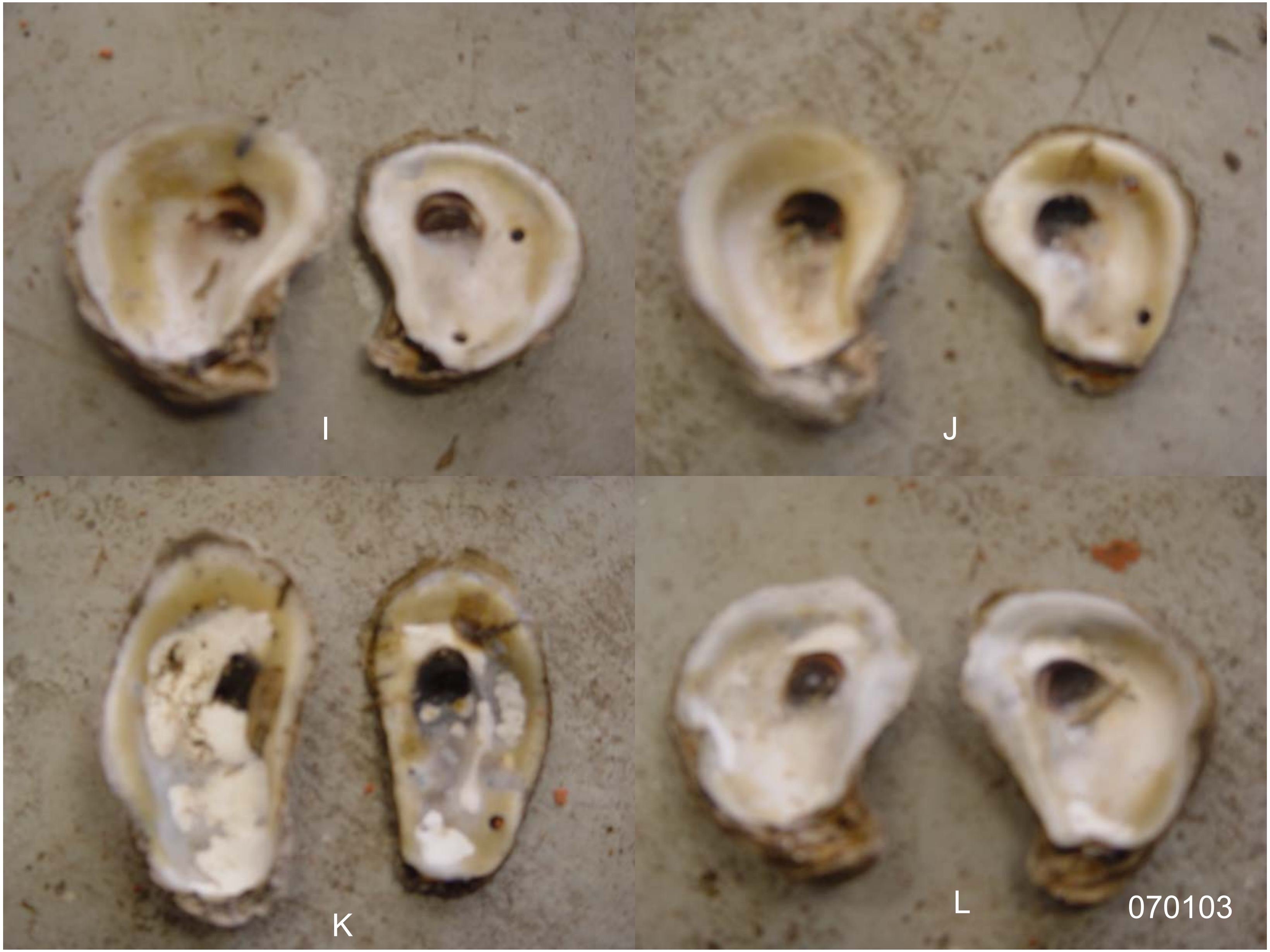

N

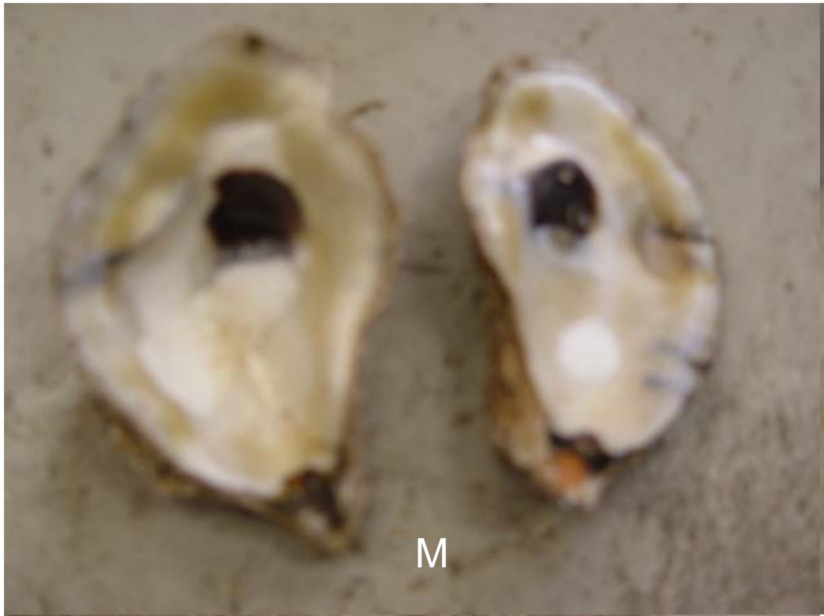

O

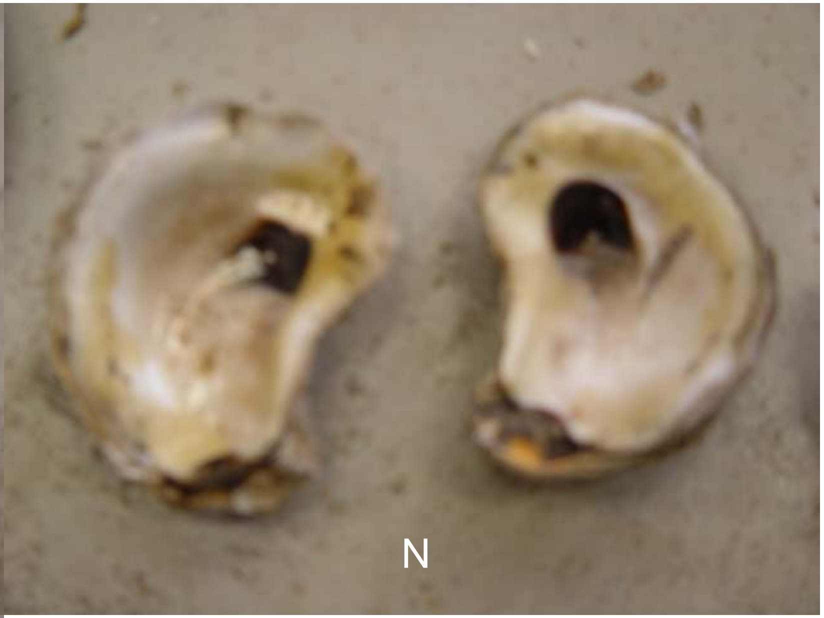
063003

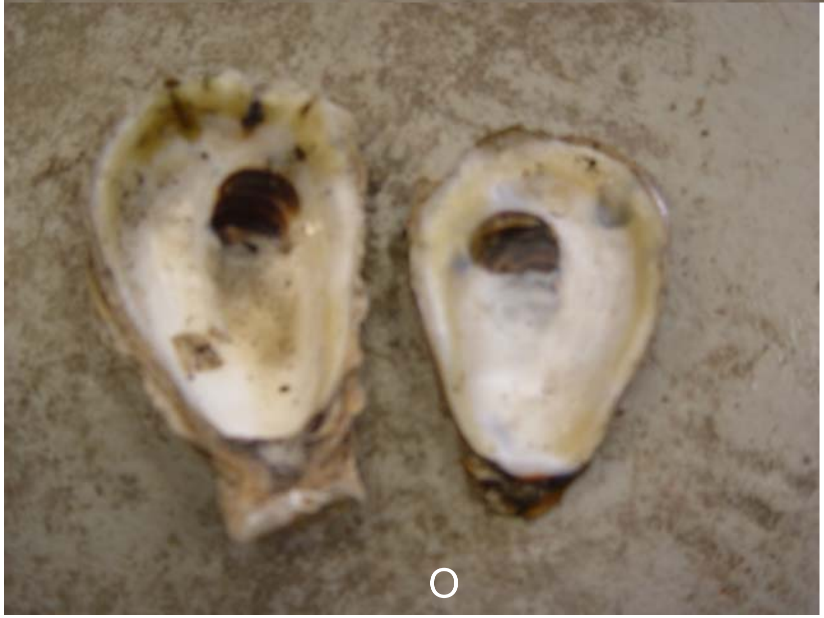

A
B
C
D
070103


E
F
G
H
070103

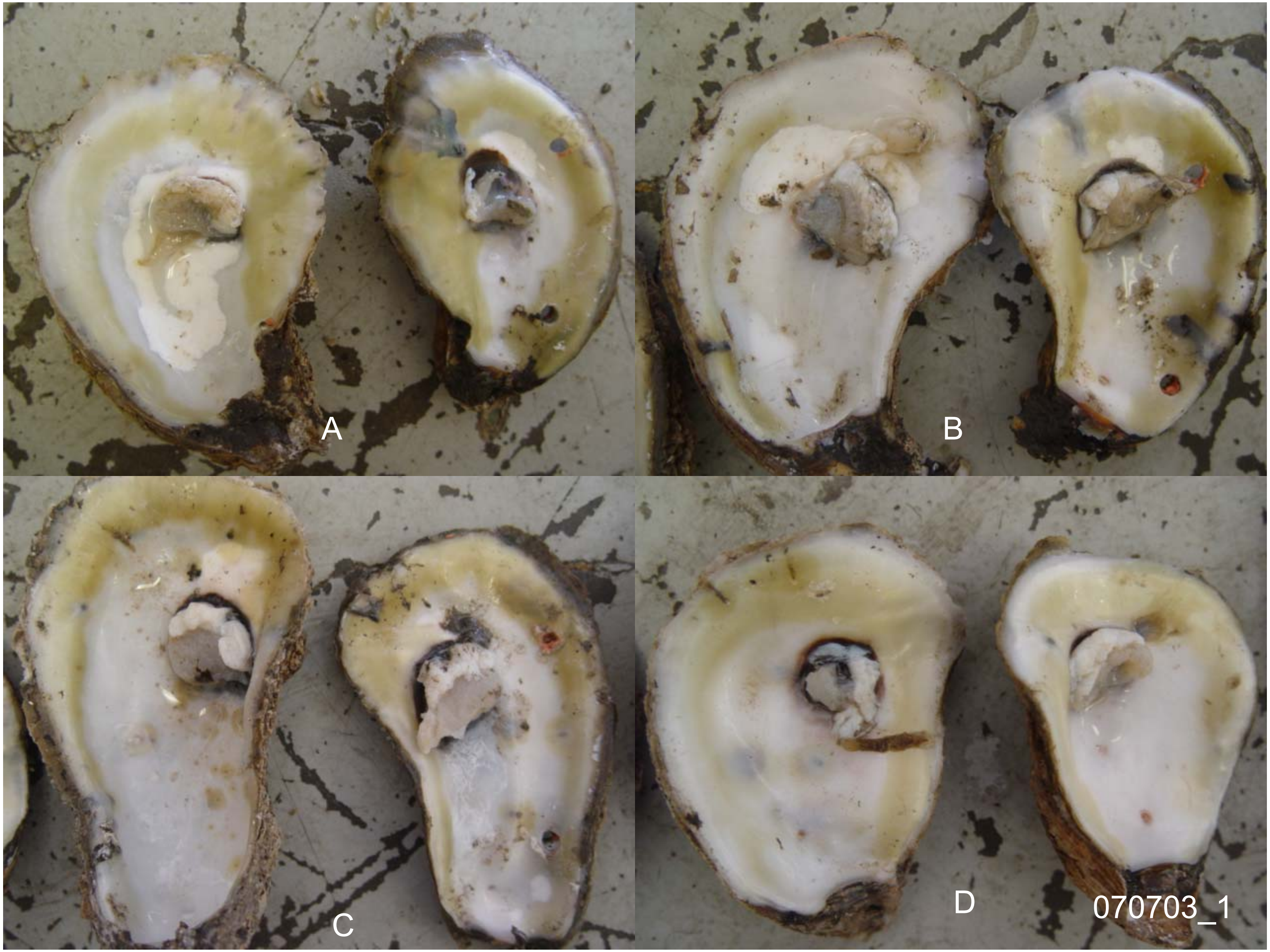

I
J
K
L
070103

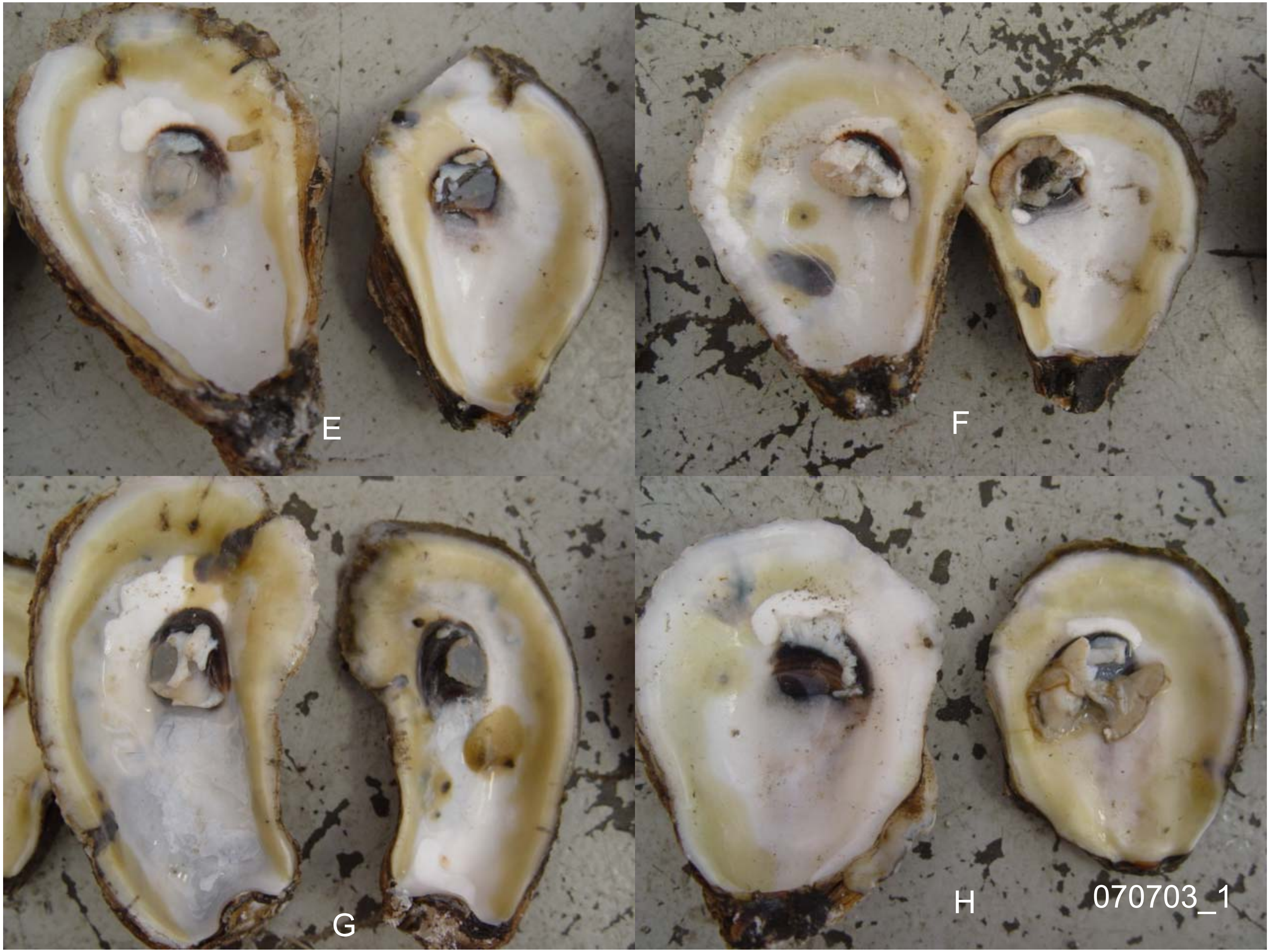


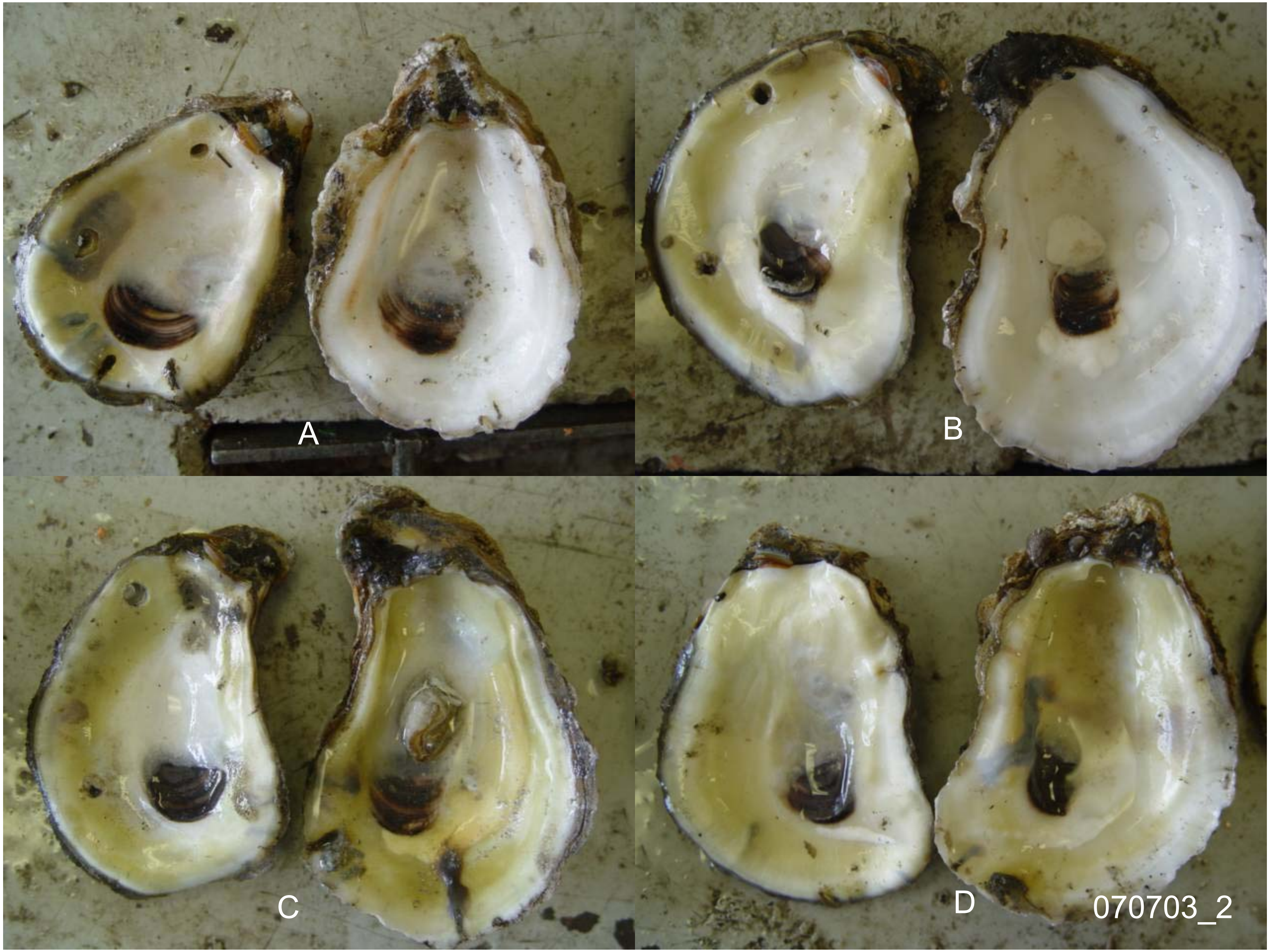




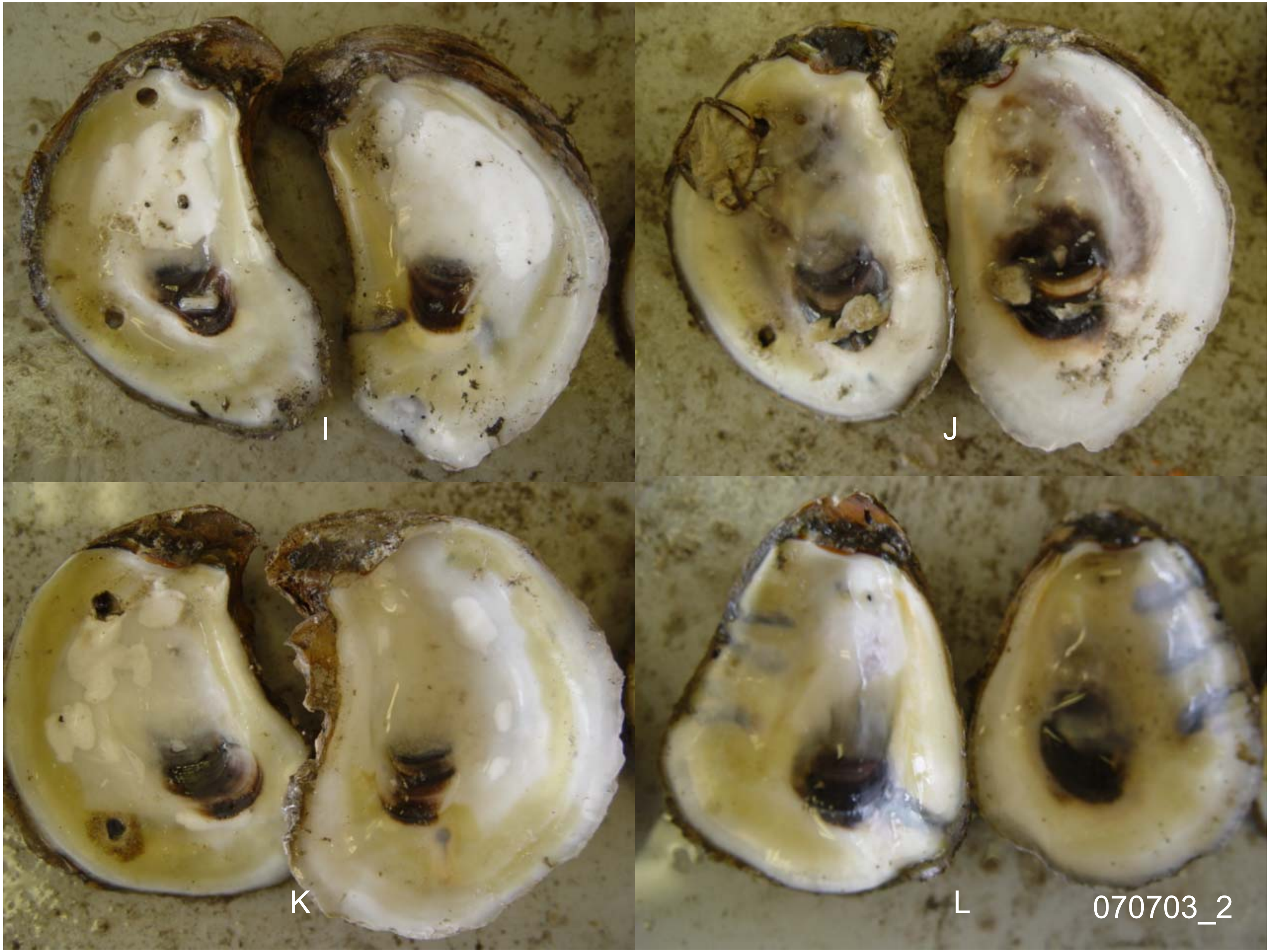
070103

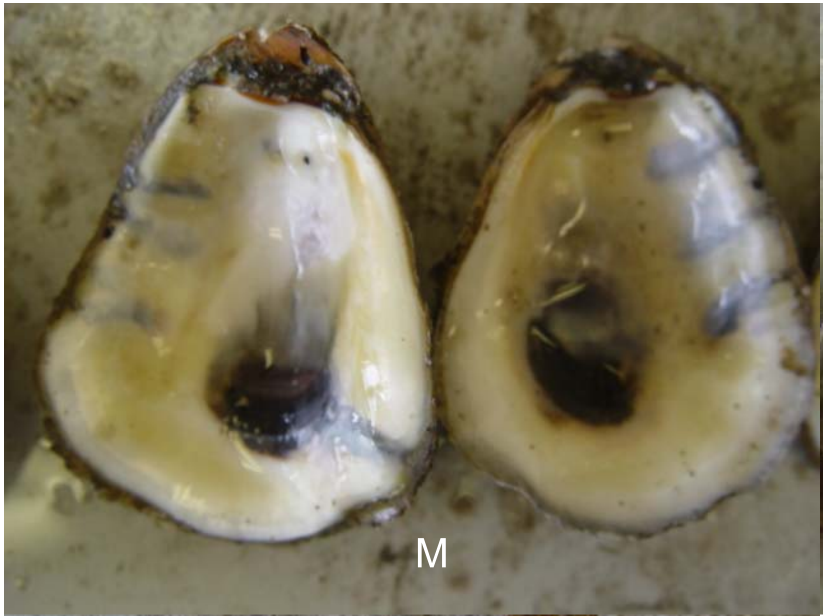

A
B
C
D
070703_1


E
F
G
H
070703_1


A
B
C
D
070703_2

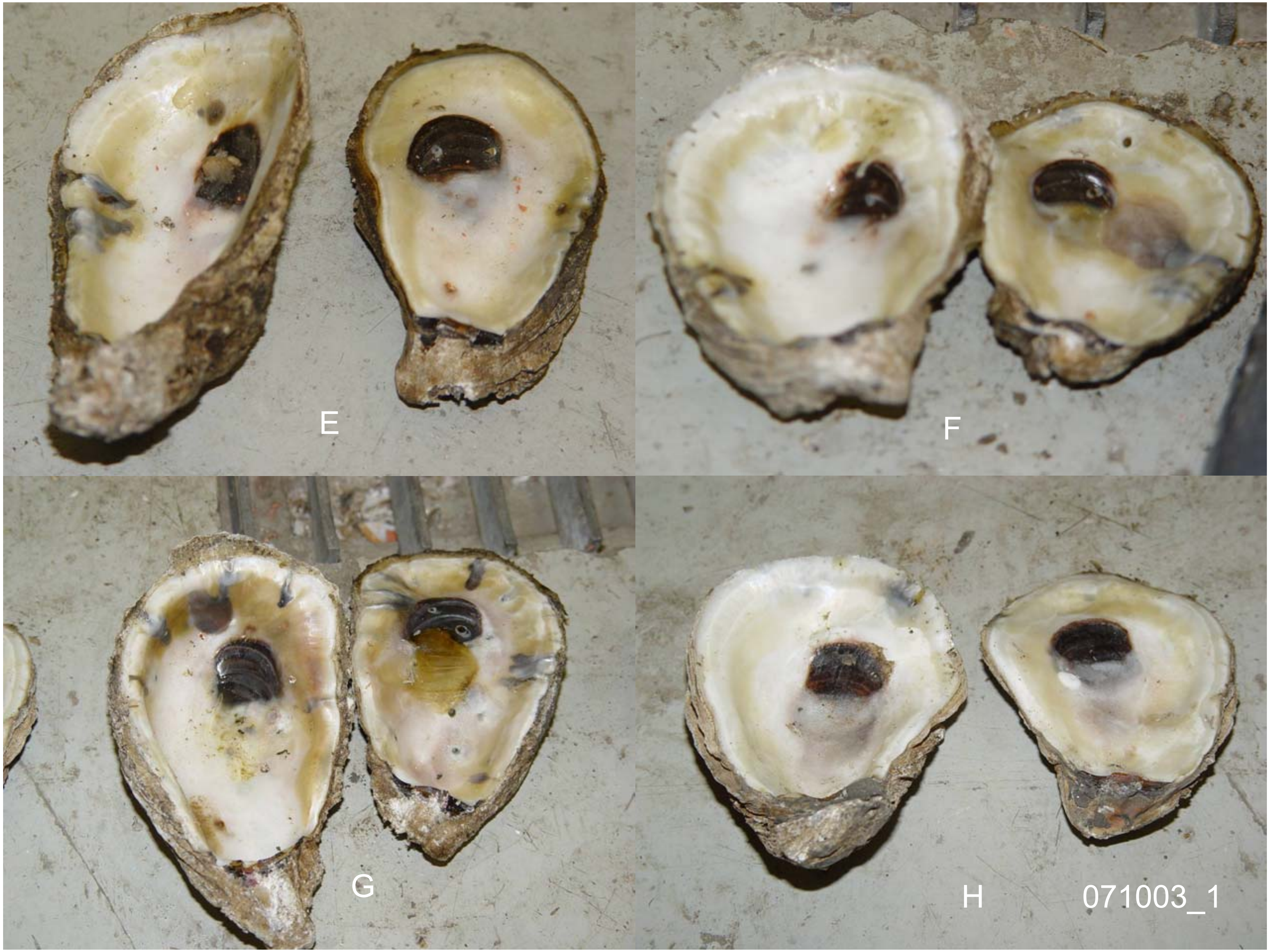

E
F
G
H
070703_2


I
J
K
L
070703_2



070703_2


A
B
C
D
071003_1


E
F
G
H
071003_1


I
J
K
L
071003_1


A
B
C
D
071003_2


E
F
G
H
071003_2


I
J
K
L
071003_2

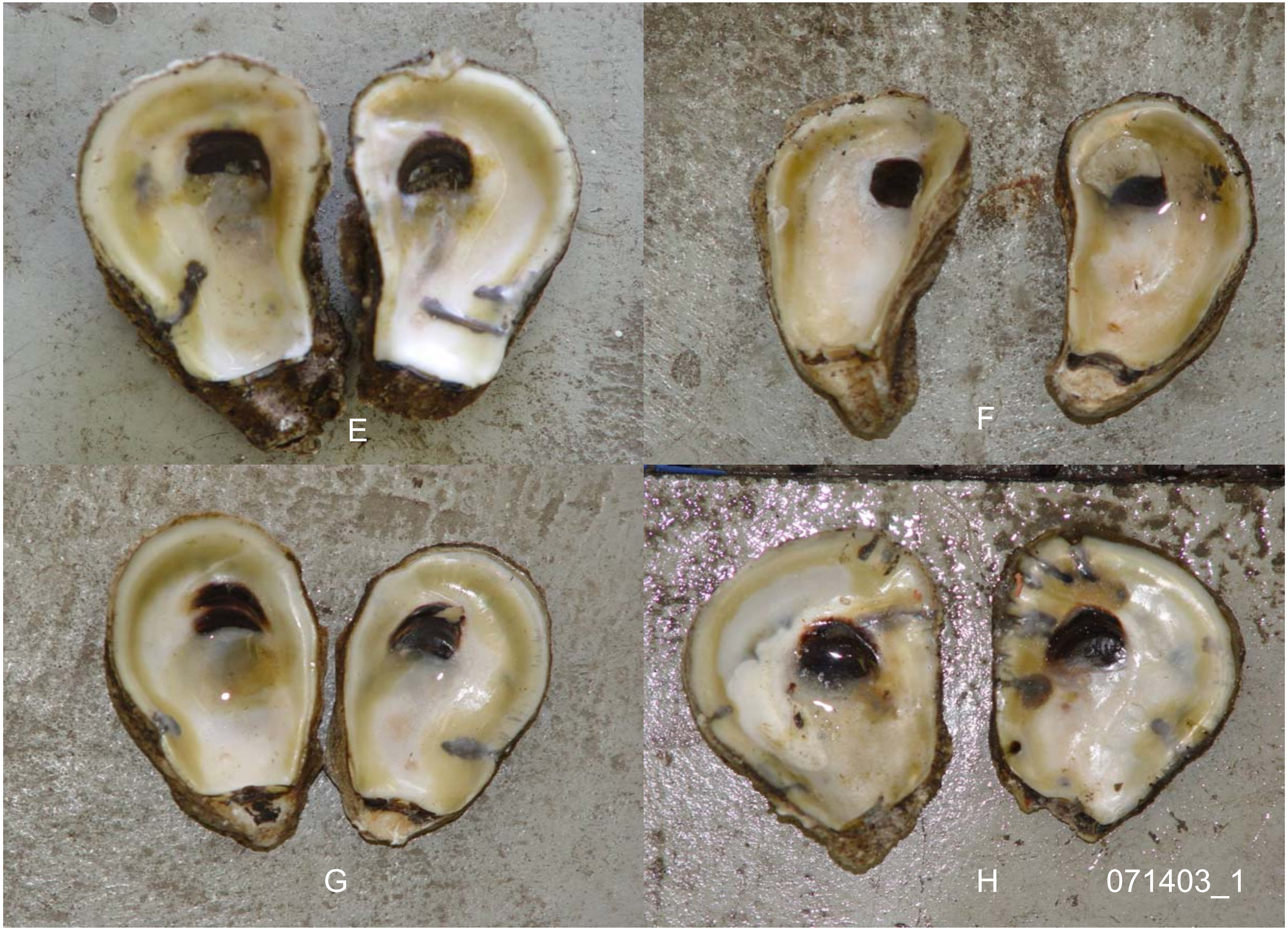

M

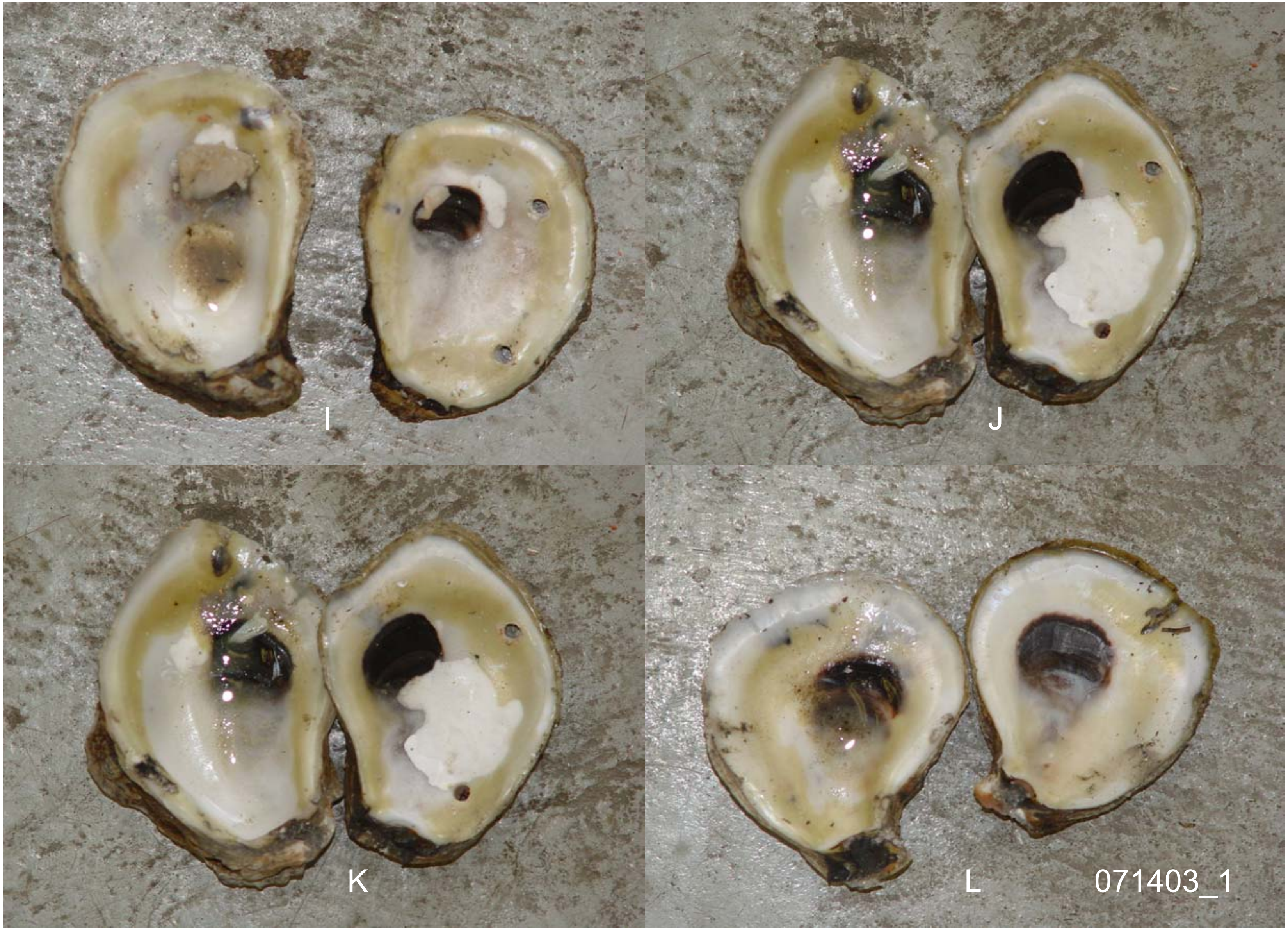

N


O

071003_2


A
B
C
D
071403_1


E
F
G
H
071403_1

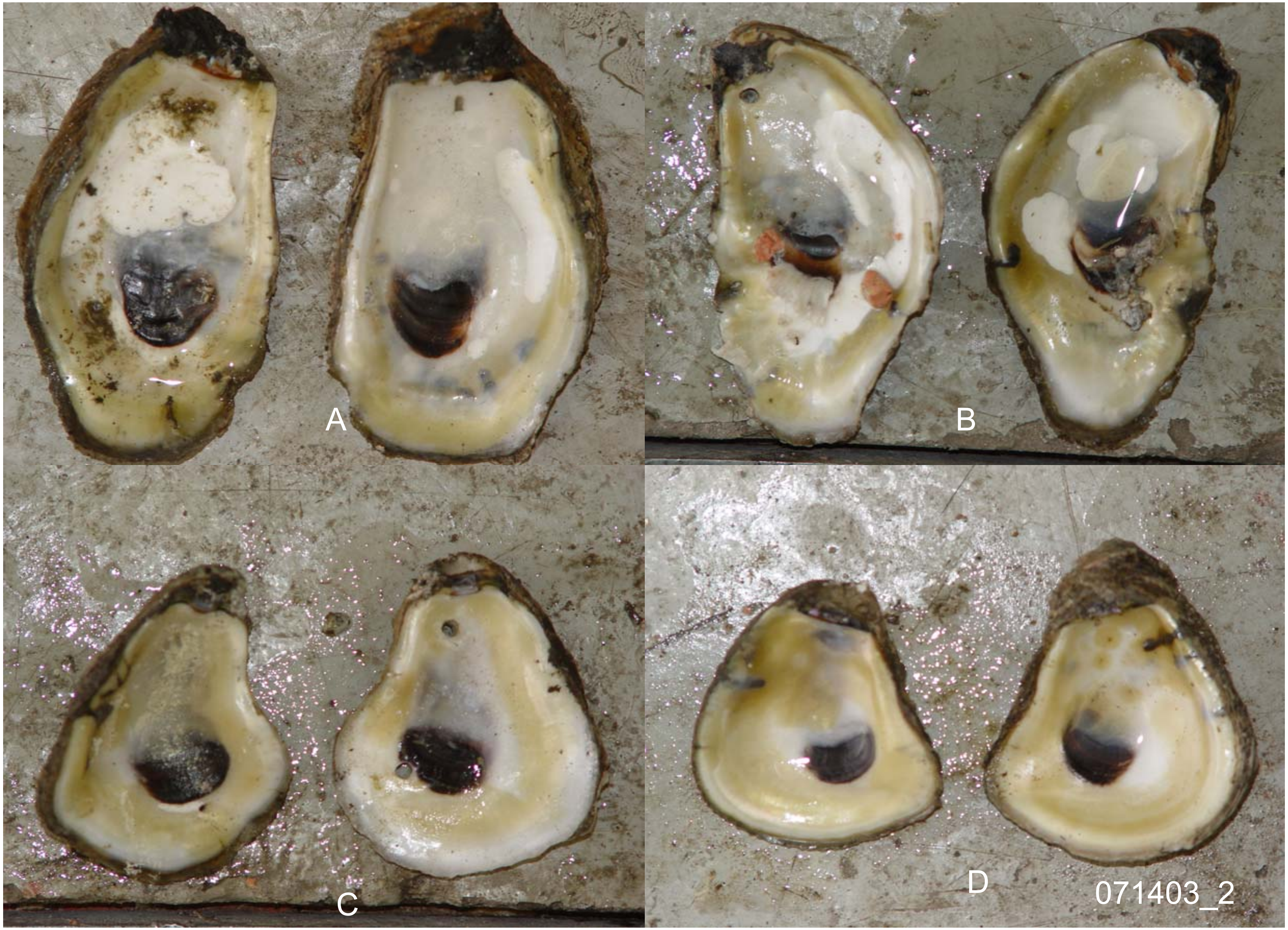

I
J
K
L
071403_1


M


N


O

071403_1


A
B
C
D
071403_2


E
F
G
H
071403_2


I
J
K
L
071403_2


M

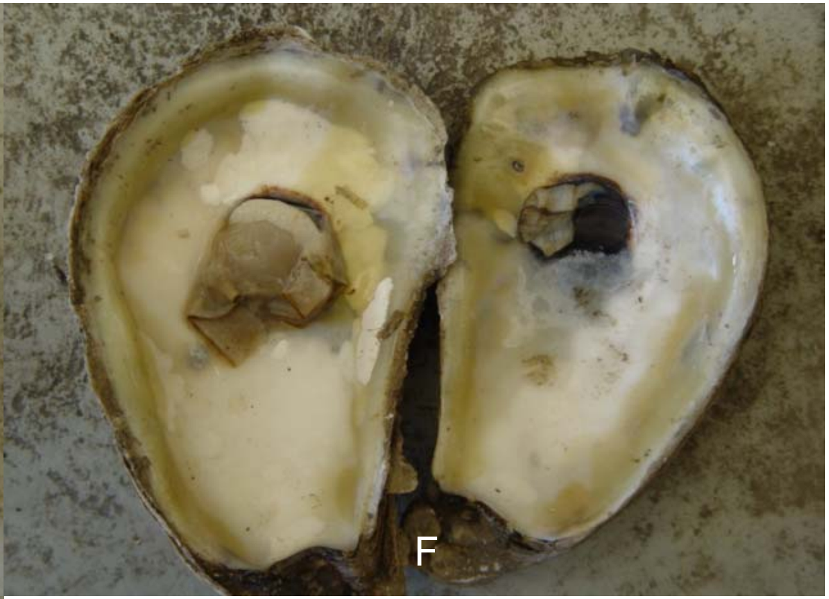

N


O

071403_2

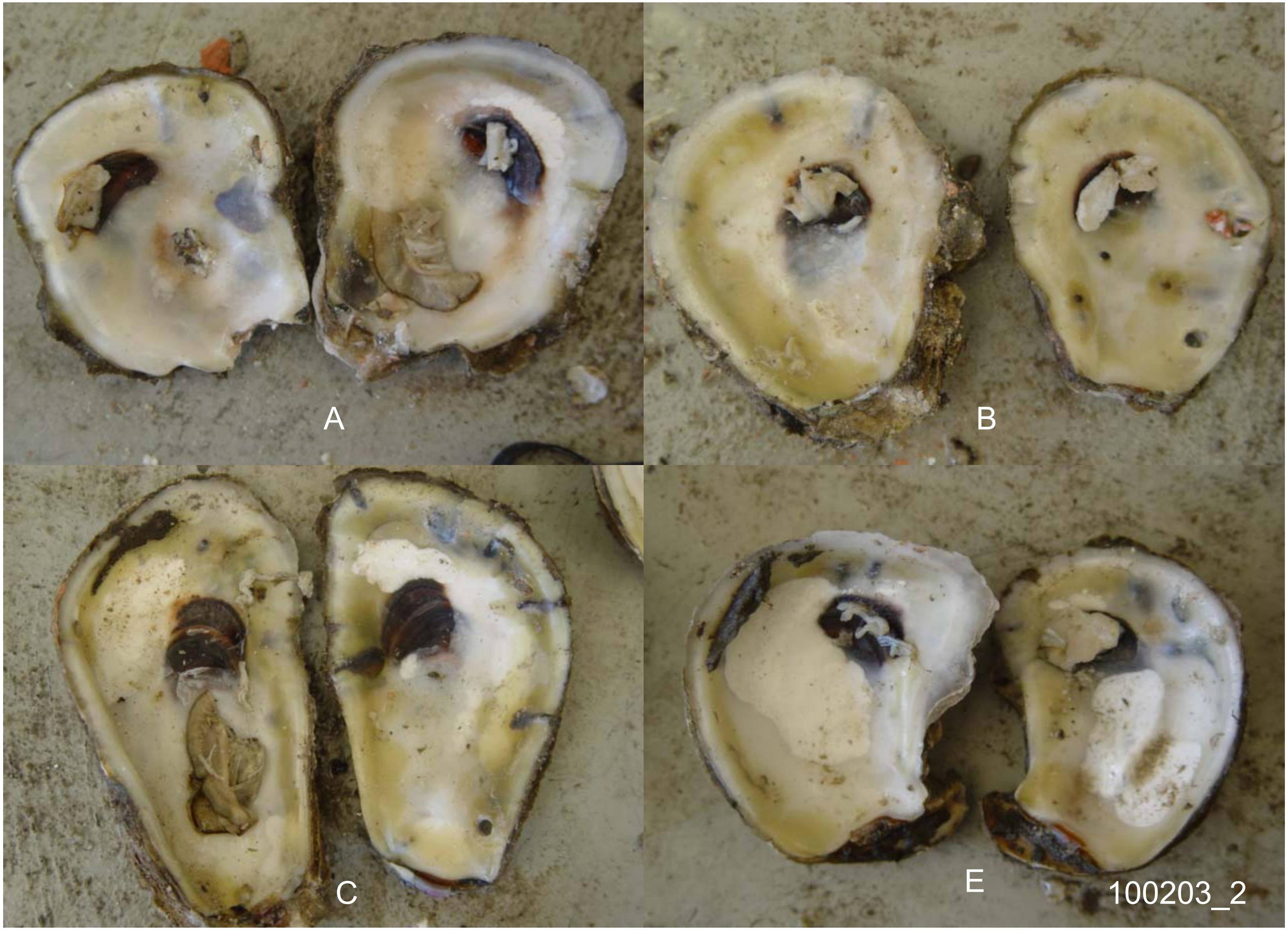

A
B
C
D
100203_1

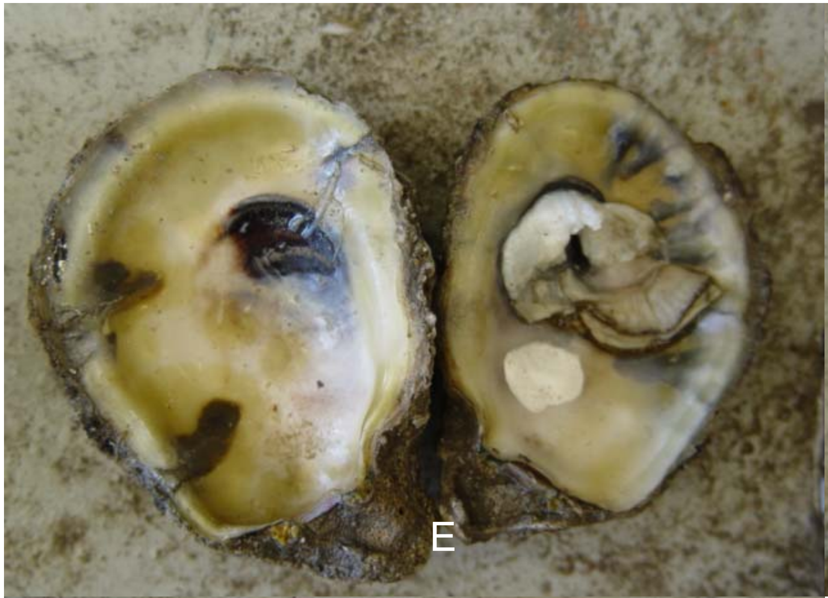

E

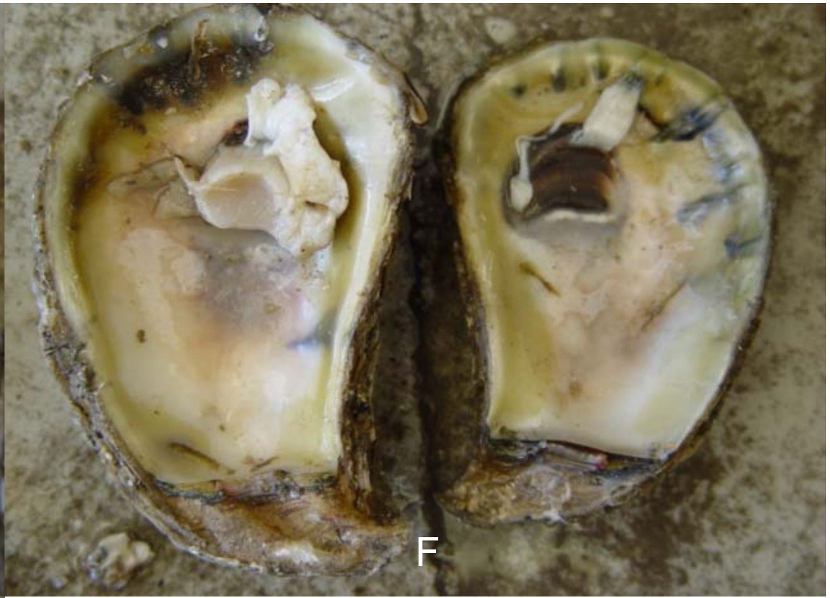

F

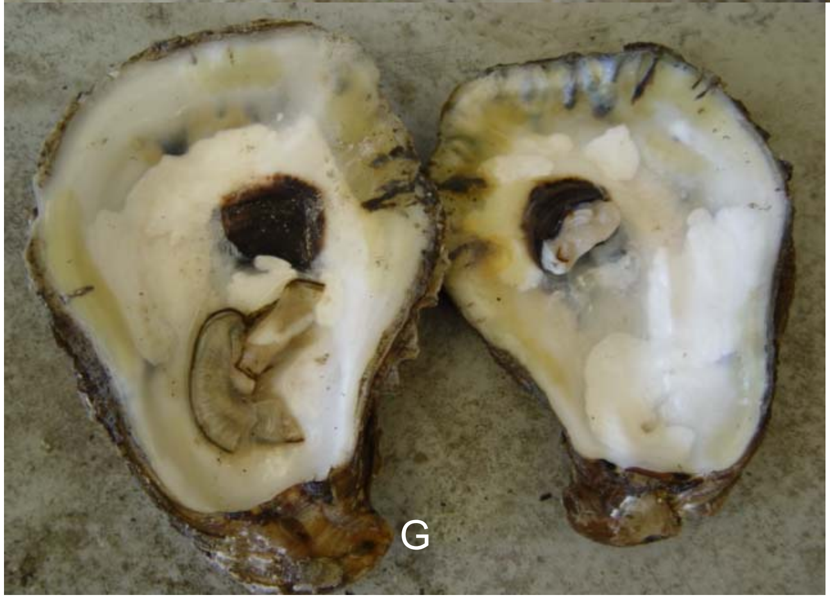

G

100203_1


A
B
C
E
100203_2







100203_2

Appendix C. Processing Data Sheets

This appendix contains the data sheets for all of the oyster shucking treatments. Shell dimensions are in millimeters. The values listed under opaque and translucent are release values, rated from 0 (full release) to 3 (no release). Relaxation values go from 0 (no relaxation) to 3 (fully gaped). The quality of the oyster meat is rated from 1 (raw) to 3 (cooked). A value of 2 was deemed acceptable. The ARV is the Average Release Value, which is the average of the release values for both the left and right valve for both the opaque and translucent mus cles.

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
091802_1				15		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	76.2	101.6	88.9	88.9	88.9										
	RV	0	0	0	0	0										
Width	LV	63.5	57.15	57.15	60.33	60.33										
	RV	0	0	0	0	0										
Thickness	LV	3.175	6.35	6.35	6.35	3.175										
	RV	3.175	6.35	6.35	6.35	6.35										
Relaxed?		2.5	1	1	1	1										
Opaque	LV	0	0	0	0	1.5										
	RV	0	1.5	3	3	3										
Transluscent	LV	0	0	0	0	1										
	RV	0	1	2	2	2										
Quality		2	2	2	2	2										
Instrumented																
Comments	1,2,3 - slightly relaxed before start															
	2,3 tightened up															
	none showed any signs of dessication/rupture/cooking															
	vessel temperature - 091802_01.dat															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
091802_2				15		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	95.25	88.9	101.6	95.25	88.9										
	RV	0	0	0	0	0										
Width	LV	57.15	63.5	53.975	57.15	57.15										
	RV	0	0	0	0	0										
Thickness	LV	9.525	6.35	9.525	3.175	3.175										
	RV	6.35	3.175	6.35	*	3.175										
Relaxed?		2.5	2.5	2.5	2.5	2.5										
Opaque	LV	3	3	3	3	3										
	RV	3	3	3	3	3										
Transluscent	LV	2	2	2	2	2										
	RV	2	2	2	2	2										
Quality																
Instrumented																

Comments

*piggyback released but added to thickness off 4's shell

3,5 appear somewhat relaxed

4 has baby oyster piggyback

temperature file - 091802_02.dat

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
092402_1																
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	79.375	82.55	76.2												
	RV	0	0	0												
Width	LV	60.325	60.325	60.325												
	RV	0	0	0												
Thickness	LV	5.6642	6.35	6.985												
	RV	5.4864	6.985	5.715												
Relaxed?																
Opaque	LV															
	RV															
Transluscent	LV															
	RV															
Quality																
Instrumented																
Comments																

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
092402_2				10		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	82.55	88.9	114.3												
	RV	0	0	0												
Width	LV	53.975	57.15	50.8												
	RV	0	0	0												
Thickness	LV	8.2042	4.064	3.175												
	RV	7.62	4.445	4.445												
Relaxed?		1	1	2.5												
Opaque	LV	0	1.5	3												
	RV	3	3	3												
Transluscent	LV	0	1	2												
	RV	2	2	2												
Quality																
Instrumented																
Comments		1 had foot deformation														
	3 shriveled somewhat															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
092402_3				15		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	3.5	3.25	3.375												
	RV															
Width	LV	2	1.75	2.25												
	RV															
Thickness	LV	0.275	0.175	0.175												
	RV	0.275	0.25	0.2												
Relaxed?		2.5	2.5	1												
Opaque	LV	1.5	0	0												
	RV	1.5	1.5	0												
Transluscent	LV	1	0	0												
	RV	1	1	0												
Quality																
Instrumented																

Comments

2 shriveled

File Name		Pre-Hea	Vac	Steam		Hold		Ice								
092402_4				10		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	82.55	82.55	88.9	88.9	92.08										
	RV	0	0	0	0	0										
Width	LV	57.15	50.8	60.33	57.15	53.98										
	RV	0	0	0	0	0										
Thickness	LV	5.715	5.08	6.35	5.08	6.35										
	RV	5.08	5.715	7.62	5.08	5.715										
Relaxed?		1	1	1	2.5	1										
Opaque	LV	1.5	1.5	1.5	1.5	0										
	RV	3	3	3	3	3										
Transluscent	LV	0	0	0	0	0										
	RV	2	2	2	2	2										
Quality																
Instrumented																
Comments	4 had filmlike substance on interior															
	3 had foot attachment deformation															

File Name		Pre-Hea	Vac	Steam		Hold		Ice								
100102_1																
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	101.6	101.6	101.6												
	RV	0	0	0												
Width	LV	60.33	57.15	66.68												
	RV	0	0	0												
Thickness	LV	6.985	6.477	8.128												
	RV	8.89	8.128	7.899												
Relaxed?																
Opaque	LV															
	RV															
Transluscent	LV															
	RV															
Quality																
Instrumented																
Comments																

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
100102_2				10		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	95.25	95.25	101.6	101.6	104.8										
	RV	0	0	0	0	0										
Width	LV	57.15	69.85	57.15	60.33	53.98										
	RV	0	0	0	0	0										
Thickness	LV	4.7752	5.309	4.978	6.35	6.223										
	RV	4.1656	6.985	6.147	8.661	6.35										
Relaxed?		2.5	2.5	1	2.5	2.5										
Opaque	LV	0	3	1.5	0	0										
	RV	0	3	3	1.5	1.5										
Transluscent	LV	0	2	1	0	0										
	RV	0	2	2	1	1										
Quality																
Instrumented																
Comments																

Random selection out of ice chest.

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
100102_03																
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	101.6	95.25	95.25	101.6	108										
	RV	0	0	0	0	0										
Width	LV	57.15	57.15	60.33	57.15	73.03										
	RV	0	0	0	0	0										
Thickness	LV	7.1628	5.715	5.08	5.461	6.223										
	RV	4.953	4.978	4.978	5.842	9.652										
Relaxed?		2.5	2.5	2.5	1	1										
Opaque	LV	3	3	3	1.5	3										
	RV	1.5	0	1.5	0	1.5										
Transluscent	LV	2	2	2	1	2										
	RV	1	0	1	0	1										
Quality																
Instrumented																

Comments

Random selection out of ice chest.

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
100202_1																
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	95.25	95.25	85.73												
	RV	0	0	0												
Width	LV	57.15	57.15	57.15												
	RV	0	0	0												
Thickness	LV	4.0386	6.782	5.486												
	RV	5.588	5.994	5.639												
Relaxed?																
Opaque	LV															
	RV															
Transluscent	LV															
	RV															
Quality																
Instrumented																
Comments																

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
100202_2				10		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	95.25	88.9	101.6	95.25	108										
	RV	0	0	0	0	0										
Width	LV	73.025	60.33	57.15	69.85	57.15										
	RV	0	0	0	0	0										
Thickness	LV	5.0292	5.461	8.23	5.436	6.706										
	RV	4.826	4.978	8.153	6.502	9.322										
Relaxed?		2.5	1	1	1	1										
Opaque	LV	3	0	0	0	3										
	RV	3	3	3	0	3										
Transluscent	LV	2	0	0	0	2										
	RV	2	2	2	0	2										
Quality																
Instrumented																
Comments																

B - frothy

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
100202_3				15		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	88.9	88.9	95.25	95.25	98.43										
	RV	0	0	0	0	0										
Width	LV	60.325	57.15	60.33	57.15	63.5										
	RV	0	0	0	0	0										
Thickness	LV	6.7564	4.089	6.528	5.004	8.179										
	RV	7.2644	6.274	6.325	5.207	6.909										
Relaxed?		1	1	1	1	1										
Opaque	LV	0	3	0	0	0										
	RV	0	3	0	0	3										
Transluscent	LV	0	2	0	0	0										
	RV	0	2	0	0	2										
Quality																
Instrumented																
Comments																

D,E - shriveling up

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
100902_1				20		60										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	88.9	76.2	92.08	88.9	85.73										
	RV	0	0	0	0	0										
Width	LV	57.15	57.15	53.98	50.8	57.15										
	RV	0	0	0	0	0										
Thickness	LV	6.477	5.309	3.683	5.588	6.35										
	RV	5.6134	6.756	5.41	5.461	7.493										
Relaxed?		2.5	2.5	2.5	2.5	1										
Opaque	LV	1.5	3	0	3	1.5										
	RV	3	3	1.5	3	3										
Transluscent	LV	1	2	0	2	1										
	RV	2	2	1	2	2										
Quality																
Instrumented																
Comments	frozen with Nitrogen															
	steam injection															
	chilled again with nitrogen															
	no indication from battery voltage as to the cause of the spike															
	instrumented oysters did show some signs of drying															
	moisture loss due to inadequate sealing of tc hole															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
101002_1				45		60										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	79.375	92.08	88.9	88.9											
	RV	0	0	0	0											
Width	LV	50.8	50.8	53.98	50.8											
	RV	0	0	0	0											
Thickness	LV	4.699	6.35	4.013	4.267											
	RV	5.6896	5.385	4.115	3.759											
Relaxed?		2.5	2.5	2.5	2.5											
Opaque	LV	3	3	3	3											
	RV	3	3	3	3											
Transluscent	LV	2	2	2	2											
	RV	2	2	2	2											
Quality																
Instrumented																
Comments	frozen with CO2															
	steam injection															
	chilled again with CO2															
	for B,C,D - the hinges were affected more than the foot															
	tc 8 was more in soft tissue than where it should have															
	been - internal to shell															
	instrumented oysters did show some signs of drying															
	moisture loss due to inadequate sealing of tc hole															
	and rupture of soft tissue															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
101002_2				60		90										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	95.25	82.55	88.9	95.25											
	RV	0	0	0	0											
Width	LV	50.8	66.68	60.33	44.45											
	RV	0	0	0	0											
Thickness	LV	6.5278	6.172	5.893	4.394											
	RV	7.0866	7.366	5.893	5.69											
Relaxed?																
Opaque	LV	0	1.5	1.5	1.5											
	RV	3	3	3	3											
Transluscent	LV	0	1	1	1											
	RV	2	2	2	2											
Quality																
Instrumented																

Comments	frozen with CO2
	steam injection
	chilled again with CO2
	tc3 pushed through tissue and onto inner shell
	tc6 was in tissue during heating but retracted when
	muscle shrank
	instrumented oysters did show some signs of drying
	moisture loss due to inadequate sealing of tc hole
	and rupture of soft tissue

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
101602_1				5		60										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	101.6	108	111.1	108	101.6										
	RV	0	0	0	0	0										
Width	LV	60.325	69.85	69.85	63.5	66.68										
	RV	0	0	0	0	0										
Thickness	LV	6.096	5.664	7.62	7.772	6.807										
	RV	5.8674	9.119	8.153	8.23	8.407										
Relaxed?		1	1	1	2.5	1										
Opaque	LV	3	3	3	3	3										
	RV	3	3	3	3	3										
Transluscent	LV	2	2	2	2	2										
	RV	2	2	2	2	2										
Quality																
Instrumented																
Comments	not very easy to open any of them															
	oyster held on tight any heat transferred into oyster did															
	not do a thing to affect the release															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
101602_2				15		60										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	95.25	101.6	108	114.3	101.6										
	RV	0	0	0	0	0										
Width	LV	66.675	57.15	73.03	66.68	69.85										
	RV	0	0	0	0	0										
Thickness	LV	8.9662	5.791	7.112	6.299	7.163										
	RV	9.7282	6.375	7.798	8.814	6.807										
Relaxed?		1	1	1	1	2.5										
Opaque	LV	0	3	3	0	3										
	RV	3	3	3	3	3										
Transluscent	LV	0	2	2	0	2										
	RV	2	2	2	2	2										
Quality																
Instrumented																
Comments	-14.2															
	26.2															
	1.2															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
101602_3				15		90										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	127	95.25	101.6	114.3	101.6										
	RV	0	0	0	0	0										
Width	LV	57.15	63.5	66.68	63.5	66.68										
	RV	0	0	0	0	0										
Thickness	LV	6.8072	9.677	4.597	6.858	7.188										
	RV	6.4516	6.604	9.017	6.68	9.703										
Relaxed?		1	1	2.5	2.5	1										
Opaque	LV	1.5	3	3	1.5	0										
	RV	3	3	3	3	3										
Transluscent	LV	1	2	2	1	0										
	RV	2	2	2	2	2										
Quality																
Instrumented																
Comments	-14.2															
	26.1															
	ina															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
101702_1				15		120										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	107.95	108	120.7	108	114.3										
	RV	0	0	0	0	0										
Width	LV	79.375	79.38	76.2	79.38	76.2										
	RV	0	0	0	0	0										
Thickness	LV	4.8514	11.13	8.153	5.664	5.486										
	RV	8.9154	7.976	8.179	7.899	8.763										
Relaxed?		2.5	2.5	1	2.5	2.5										
Opaque	LV	1.5	1.5	1.5	0	0										
	RV	1.5	3	3	3	3										
Transluscent	LV	1	1	1	0	0										
	RV	1	2	2	2	2										
Quality																
Instrumented																
Comments	while not relaxed, the oysters were not very resistant to being opened. After searching for a entry point and applying some force, the oysters opened but still did not release															

File Name		Pre-Heat	Vac	Steam		Hold		Ice							
101702_02				15		60									
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N
Banded															
Side Down															
Height	LV	114.3	101.6	104.8	108	92.08									
	RV	0	0	0	0	0									
Width	LV	63.5	66.68	60.33	66.68	60.33									
	RV	0	0	0	0	0									
Thickness	LV	3.7592	5.69	8.153	4.724	9.677									
	RV	5.8674	6.045	9.855	5.385	8.28									
Relaxed?		2.5	2.5	2.5	2.5	2.5									
Opaque	LV	1.5	1.5	0	0	0									
	RV	1.5	1.5	3	3	1.5									
Transluscent	LV	1	1	0	0	0									
	RV	1	1	2	2	1									
Quality															
Instrumented															
Comments	10sec steam with vent open														
	vent closed and vacuum pulled to -14.2psi														
	15 sec steam inj with 60 sec hold														

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
101802_1				15		60										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	101.6	101.6	108	127	114.3										
	RV	0	0	0	0	0										
Width	LV	85.725	76.2	60.33	69.85	76.2										
	RV	0	0	0	0	0										
Thickness	LV	5.8928	10.82	5.004	7.874	5.08										
	RV	5.9944	9.55	7.899	8.611	4.496										
Relaxed?		2.5	2.5	2.5	2.5	2.5										
Opaque	LV	3	3	3	0	3										
	RV	3	3	3	1.5	3										
Transluscent	LV	2	2	2	0	2										
	RV	2	2	2	1	2										
Quality																
Instrumented																
Comments	C internal shell tc was actually inside adductor muscle															
	20 sec steam with vent open															
	pulled -12.6psi vacuum															
	steam inj and hold noted above															
	B had foot deformity on shell															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
102202_1				10		60										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	3.75	4	3.75	4.25	4.25										
	RV															
Width	LV	2.75	2.5	2.5	3	2.5										
	RV															
Thickness	LV	0.250	0.336	0.211	0.238	0.247										
	RV	0.278	0.203	0.243	0.201	0.281										
Relaxed?		2.5	2.5	1	2.5	1.5										
Opaque	LV	0	1	1	1	1.5										
	RV	1	3	3	1	1										
Transluscent	LV	0	0	0	0	1										
	RV	0	3	3	0	0										
Quality																
Instrumented																
Comments	C,E relaxed before start															
	C released a lot of water															
	A,C,E held shut with rubberband															
	Rubberband on A fell off															
	all instrumented oysters were ruptured due to tc															
	sensory tentacles affected in all, no so much in E															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
102302_1				10		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	4.5	4.5	4.125	4.875	4.5										
	RV															
Width	LV	2.625	2.75	2.75	2.626	3										
	RV															
Thickness	LV	0.227	0.185	0.279	0.255	0.212										
	RV	0.310	0.222	0.447	0.302	0.369										
Relaxed?		2.5	2.5	1	2.5	1.5										
Opaque	LV	1	3	0	0	0										
	RV	2	3	3	1.5	2										
Transluscent	LV	0	3	0	0	0										
	RV	1.5	3	3	0	1.5										
Quality																
Instrumented																
Comments	rubber band on A fell off															
	vacuum valve open for preheat															
	nr/r2 means no release at first but released															
	after a 2 minute wait															
	no/o4 means no opening at first but open after 4 minutes															
	release designation - 0-not released 10-full release															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
102402_1				5		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	4.25	4.5	4.5	4.375	4.5										
	RV															
Width	LV	2.75	2.5	2.75	2.5	2.75										
	RV															
Thickness	LV	0.306	0.401	0.252	0.280	0.383										
	RV	0.450	0.392	0.332	0.191	0.454										
Relaxed?		2.5	1	1	2.5	1										
Opaque	LV	0	1.5	0	3	3										
	RV	3	3	1.5	3	3										
Transluscent	LV	0	0	0	3	3										
	RV	3	3	5	3	3										
Quality																
Instrumented																

Comments

Rubber bands on D,E

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
102402_2				5		60										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	4.25	4	4.25	4	4										
	RV															
Width	LV	2.75	3.25	2.75	2.75	1.375										
	RV															
Thickness	LV	0.267	0.181	0.15	0.242	0.142										
	RV	0.203	0.155	0.262	0.339	0.255										
Relaxed?		2.5	1	1	2.5	1										
Opaque	LV	0	1.5	3	0	0										
	RV	1	1.5	3	1.5	2										
Transluscent	LV	0	0	3	0	0										
	RV	0	0	3	0	1.5										
Quality																
Instrumented																
Comments																
	Rubber bands on D,E															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
1025_01				10		60										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	4	3.75	4.25	5	4.5										
	RV															
Width	LV	2.25	2.375	2.5	2.75	3										
	RV															
Thickness	LV	0.153	0.144	0.218	0.212	0.329										
	RV	0.174	0.178	0.279	0.296	0.361										
Relaxed?		2.5	2.5	2.5	2.5	1.5										
Opaque	LV	0	1	0	0	1										
	RV	1	2	0	0	3										
Transluscent	LV	0	0	0	0	0										
	RV	0	1.5	0	0	3										
Quality																
Instrumented																

Comments

all oyster were in fairly good condition, most however did show some fringe damage oysters were not bound or instrumented.oysters subjected to vitrodyne analysis.

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
cryo_1																
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	95.25	101.6													
	RV	0	0													
Width	LV	60.325	50.8													
	RV	0	0													
Thickness	LV	6.0452	3.962													
	RV	6.8326	4.115													
Relaxed?																
Opaque	LV	1.5	0													
	RV	0	1.5													
Transluscent	LV	1	0													
	RV	0	1													
Quality																
Instrumented																
Comments	cryo set pt. -58F -50C															
	100702_1.dat															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
cryo_2																
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	88.9	101.6													
	RV	0	0													
Width	LV	57.15	63.5													
	RV															
Thickness	LV															
	RV															
Relaxed?																
Opaque	LV															
	RV															
Transluscent	LV															
	RV															
Quality																
Instrumented																
Comments	cryo set pt. -58F -50C															
	100702_2.dat															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
cryo_3				15		30										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	92.075	92.08													
	RV	0	0													
Width	LV	60.325	0													
	RV	0	0													
Thickness	LV	4.9784	6.985													
	RV	4.445	6.35													
Relaxed?																
Opaque	LV	0	0													
	RV	0	3													
Transluscent	LV	0	0													
	RV	0	2													
Quality																
Instrumented																
Comments	removed and frozen at -50C															
	cryo set pt. -58F -50C															
	100702_3.dat															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
cryo_4				15		45										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down																
Height	LV	76.2	88.9													
	RV	0	0													
Width	LV	76.2	63.5													
	RV	0	0													
Thickness	LV	6.5532	4.597													
	RV	4.826	5.41													
Relaxed?																
Opaque	LV	0	3													
	RV	1.5	1.5													
Transluscent	LV	0	2													
	RV	1	1													
Quality																
Instrumented																
Comments	removed and frozen at -50C															
	oyster A tc fell out during transfer to cryo															
	cryo set pt. -58F -50C															
	100702_4.dat															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
060503_1				90		60		120								
SIZE		L	L	S	L	L	M	M								
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		y	y	y	y	y	y	y								
Side Down																
Height	LV	101.3	130.9	79	114	105	88	89								
	RV	88.4	144.7	75	111	102	92	88								
Width	LV	67	77	52	69	61	51	57								
	RV	64	80	55	70	57	48	58								
Thickness	LV	9.9	5.5	5.1	9.6	9.5	6.7	6.5								
	RV	7.6	6.9	4.5	10.1	8.4	5.5	7.6								
Relaxed?		0	0	0	1	1.5	2	1								
Opaque	LV	n	n	n	n	n	n	y								
	RV	y	y	y	n	n	y	n								
Transluscent	LV	y	n	y	y	y	y	y								
	RV	y	y	y	y	y	y	y								
ARV																
Quality		2.5	2	3	1.5	1.5	1.5	2								
Instrumented		y	y	y	n	n	n	n								
Comments																

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
060503_2				60				120								
SIZE		M	S	L	M	L	M	L								
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		y	y	y	n	n	n	n								
Side Down																
Height	LV	93	77	108	87.0	102	87	101								
	RV	80	70	90	84.0	73	85	93								
Width	LV	61	55	64	49.0	57	61	73								
	RV	57	57	58	60.0	43	51	60								
Thickness	LV	7.6	7.5	9.4	6.3	4.4	10	9.5								
	RV	5.1	3.5	8.4	7.9	7	7.6	8.1								
Relaxed?		0.5	0.5	0	0.0	1	1	1								
Opaque	LV	0	0	0	0.0	3	0	3								
	RV	3	3	3	3.0	3	3	0								
Transluscent	LV	3	3	3	3.0	0	0	0								
	RV	3	3	3	0.0	0	0	0								
ARV		2.25	2.25	2.25	1.5	1.5	0.75	0.75								
Quality		2	2.5	2	1.5	2	2	1.5								
Instrumented	y	y	y	n	n	n	n	n								
Comments	IST slightly into tissue of A															

File Name		Pre-Heat	Vac	Steam		Hold		Ice							
060603_1		0	-8.5	90		0		120							
			1:20 m												
SIZE		L	M	S	M	L	M	S							
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N
Banded		Y	Y	Y	N	N	N	N							
Side Down					RV	LV	LV	LV							
Height	LV	97.4	95.6	82.1	88.6	99.8	97.7	73.8							
	RV	105.8	91.6	72.8	79.5	106.1	93.4	54.5							
Width	LV	50.6	60.8	65.1	74.7	60.2	54.5	51.4							
	RV	55.5	67.7	60.5	58.8	67	51	46.9							
Thickness	LV	7.3	8.4	6	8.5	6.6	10.3	7							
	RV	9.3	9.6	6.1	7.5	5.4	9.7	4							
Relaxed?	(0-2)	0	0	0	1	1	0	0.5							
Opaque	LV	1	1	1	2	1	3	1							
(0-3)	RV	3	1	1	1	0	2	3							
Transluscent	LV	Y	Y	Y	Y	Y	3	0							
(0-3)	RV	Y	Y	Y	Y	Y	0	1							
ARV															
Quality		2	1.2	1.7	1.5	1	1	1.5							
(0-3)															
Instrumented		Y	Y	Y	N	N	N	N							
Comments	Clay on the inside shell thermo couple for the second oyster came off.														

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
060603_2			-8.5	120 sec				120								
			1:52	56 psi												
SIZE		M	M	L	L	L	M	L								
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded																
Side Down		LV	LV	LV	LV	LV	LV	LV								
Height	LV	94.1	90.5	102.4	113.1	142.7	90.2	107.3								
	RV	74.6	72.3	87.4	101.8	119	106.3	92.2								
Width	LV	68.4	50	61.5	71.7	57.1	65.1	74.7								
	RV	54	47.4	60	66.9	49.8	69.9	69.4								
Thickness	LV	8.4	9.4	8	7.7	2.8	6.4	5.8								
	RV	6.4	7.6	6.6	10.9	3.9	4.4	6.2								
Relaxed?		0	0	0	0	3	1	3								
Opaque	LV	0	0	0	0	1	2	3								
	RV	0	2	2	2	1	3	0								
Transluscent	LV	0	0	0	0	0	1	3								
	RV	0	2	2	2	1	2	0								
ARV		0	1	1	1	0.75	2	1.5								
Quality		2	2.5	2	1	2.5	2	2.5								
Instrumented		y	y	y	n	n	n	n								

Comments	
	IST into the muscle for B and C.

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
060903_1				120				120								
				56 psi												
SIZE		M	L	L	M	M	S	L								
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y								
Side Down																
Height	LV	96.52	104.1	132.1	93.98	93.98	81.28	121.9								
	RV	88.9	101.6	119.4	91.44	83.82	76.2	96.52								
Width	LV	71.12	60.96	58.42	58.42	66.04	58.42	66.04								
	RV	63.5	55.88	53.34	53.34	60.96	53.34	58.42								
Thickness	LV	10.16	10.16	10.16	10.16	5.08	5.08	10.16								
	RV	7.62	7.62	5.08	7.62	5.08	5.08	10.16								
Relaxed?		3	0	0	3	0	0	0								
Opaque	LV	0	3	0	0	1	2	2								
	RV	0	3	0	0	0	1	0								
Transluscent	LV	0	2	0	0	1	1	2								
	RV	0	3	0	0	0	0	0								
ARV		0	2.75	0	0	0.5	1	1								
Quality		3	2.5	2	2.5	2	1.5	2								
Instrumented		Y	Y	Y												
Comments	IST into the muscle for A,B and C															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
061203_data			-8	60		60		120								
				34 psi												
				30 psi												
SIZE		M	L	M	M	L	M	M	M	M	M	M	L	M	M	S
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		LV	LV	LV	LV	LV	LV	LV	LV	LV	LV	LV	LV	LV	LV	LV
Height	LV	96.6	103.2	93.4	92.2	100.6	88.9	93.3	89.3	90.3	88.1	85.8	113	87.8	93.8	78
	RV	81.9	88.7	81.2	81.3	89.3	82.3	86.6	75.8	77.9	79.9	78.7	94.9	77.5	89.3	66.6
Width	LV	58.3	60.5	65.4	68.8	57.4	45.1	63.7	51.2	70.1	61.3	57.4	65.7	59.1	52.8	57.5
	RV	55	55.3	54.5	58.1	54.7	44.1	57.7	45.7	67.9	59.3	54.2	54.9	52.1	45.4	51.8
Thickness	LV	5.7	3.8	6.4	6.5	7.7	8.4	5.5	7.1	5.3	7	4.4	5.9	5.9	5.8	7.3
	RV	6.4	7.1	7.5	6.5	8.2	4.8	4.6	5.6	7.9	5	6.7	5.3	5.4	6.2	6.7
Relaxed?		0	0	0	1	0	0	1	0	1	0	0	0	0	0	0
Opaque	LV	3	3	1.5	1	1	3	0.5	2	0	3	3	2	3	1	2
	RV	1	1	2	2	0	1	2	1	3	0	3	2	3	1	2
Transluscent	LV	1	1	0	0	0	3	0	0	0	3	0	1	2	0	0
	RV	3	0	0	1	0	0	2	0	0	0	0	0	1	0	0
Quality		1.7	2	2.25	1.5	2.0	2	1.5	2	2	2	2.5	2	2	1.5	1
ARV		2	1.25	0.875	1	0.25	1.75	1.125	0.75	0.75	1.5	1.5	1.25	2.25	0.5	1
Instrumented		Y	Y	Y	N	N	N	N	N	Y	Y	Y	N	N	N	N
Comments	IST into the muscle for B and I															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
61303				90		0		240								
				46,50 psi												
SIZE		M	L	L	L	L	M	S	M	M	M	L	M	S	S	S
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	90.3	118.4	102.9	113.9	104	98.6	78.1	94.3	86.7	90.9	101.3	90.4	82.1	74.2	72.6
	RV	75.7	100.6	93.2	109.5	92.8	89.8	71.5	88.8	82.3	83.9	95.2	85.2	78.7	70.8	66.4
Width	LV	57.6	66.8	63.1	48.8	68.9	56.8	53.9	74.7	55.7	56.1	51.1	77	51.3	55.6	50.3
	RV	52.4	62.3	58.4	46.2	52.5	51	49.6	67.9	47.4	50.4	47.3	67.2	47	47.7	47.4
Thickness	LV	10.8	8.9	5.2	8.9	4.5	9.1	6.3	6.9	8.1	5.9	6.3	6.4	5.6	6.1	6.2
	RV	4.9	8.7	5.4	5.4	5.4	7.9	5.3	6.3	6.9	5.2	4.9	6.9	5.4	4.7	4.4
Relaxed?		1	0	0	2	1.5	0	0	0	0	0	1	0	0	0	0
Opaque	LV	2	3	2	2	1	0	2	1	0	3	0	0	1	1	0
	RV	1	0	0	3	2	0	3	0	2	1	0	0	3	0	1
Transluscent	LV	0	0	2	1	0	0	2	0	0	0	0	0	0	0	0
	RV	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
ARV		0.75	0.75	1	1.5	0.75	0	2	0.25	0.5	1	0	0	1	0.25	0.25
Quality		3	2	2	2.0	2	1.5	3	1.5	3	3	3	1.5	3	2	3
Instrumented		Y	Y	Y						Y	Y	Y				
Comments		C1	C2	C3												
Height	LV	135.5	104.8	95.3												
	RV	114.8	104.3	85												
Width	LV	84.3	68.9	55.8												
	RV	83.2	69.4	51												
Thickness	LV	8.2	8.2	3.9												
	RV	8.7	9.3	5												

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
61603				120		0		240								
				56,50												
SIZE		M	M	L	L	M	S	S	M	L	M	M	S	S	M	S
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		y	y	y	y	y	y	y	y	y	y	y	y	y	y	y
Side Down		L	L	L	L	L	L	L	L	L	L	R	L	L	L	L
Height	LV	91.6	85.2	123.6	104.8	96.6	81.9	78.4	86.8	110.8	95.1	96.5	83.6	66	87.7	82.4
	RV	90.2	82.9	108.7	96.5	86.6	79.6	67.8	76.6	98	86.1	89.2	81.4	63.3	78.4	79.7
Width	LV	59.5	55	62.7	54	62.7	58.2	59	66	60.5	73.8	66.7	70.1	57.7	57.5	52
	RV	52.5	53.6	53.6	52.1	56.9	54.1	52.9	54.4	57.6	68.2	58.3	63.2	50.2	65	47.3
Thickness	LV	5	8.6	7.7	6.5	6.6	6.5	5.4	6.7	7.4	4.9	6	6.8	8.5	5.6	4.3
	RV	5.6	8	6.9	4.6	4.8	5.6	6	8	7.5	5	6	4.3	6	5.6	6.6
Relaxed?		2	0.5	2	1	0	0	0	0.5	2	3	2	1	0	1	0
Opaque	LV	0	0	0	0	0	2	1	0	0	3	0	1	0	3	0
	RV	0	0	0	2	0	0	1	0	0	0	0	0	0	2	3
Transluscent	LV	0	0	0	2.5	0	0	0	0	0	0.5	0	0	0	0	0
	RV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quality		3	3	3	3	3	3	3	3	3	3	3	3	3	2.5	3
ARV		0	0	0	1.125	0	0.5	0.5	0	0	0.875	0	0.25	0	1.25	0.75
Instrumented		Y	Y	Y						Y	Y	Y				
Comments	IST into the muscle for C and K; band broke for L.															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
61703				90		60		240								
				47,50												
SIZE		M	M	M	S	S	L	M	S	L	S	M	S	M	S	S
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	94.3	92.8	89.3	80.1	76	103.6	93.3	78.5	109.7	79.8	95.4	79.7	92.5	71.1	77.6
	RV	79.7	74.1	77.1	74.5	64.1	98.4	83.6	69.4	95.7	79	98.4	75.4	83.6	57.6	69.6
Width	LV	53.7	63.8	62.7	60.8	47.7	60.8	69.3	57.5	56	50.7	57	62	59.6	55.2	56.9
	RV	46.9	58.2	52	51.7	47	51.1	66.5	50.4	50	49.6	47.1	57.7	56.9	49.8	52
Thickness	LV	5.8	6.3	5.4	8.1	6	7.4	6.2	6.1	6.9	5.7	11.7	8	8.7	4.8	4
	RV	3.8	5.9	5.8	6.9	6.6	3.9	5.3	4.7	5.7	5.3	7.2	7.6	7.6	5.4	6.7
Relaxed?		0	0	1	0	1	0	0	0	2	1	1	0	0	3	0
Opaque	LV	1	0	0	1	1	0	0	0	2	0	0	0	0	0	0
	RV	0	0	0	3	2	0	0	0	1	0	0	0	2	0	0
Transluscent	LV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quality		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
ARV		0.25	0	0	1	0.75	0	0	0	0.75	0	0	0	0.5	0	0
Instrumented		Y	Y	Y					Y	Y	Y					
Comments	IST into the muscle for oyster A,oyster N band broke.															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
61803				60		90		240								
				30,27												
SIZE		S	S	L	S	L	L	S	M	S	S	S	S	L	S	M
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	84.1	76.5	102.5	79.6	100.3	115.8	79.3	91.4	75.3	79.8	84.7	84.8	104.1	81.7	99.1
	RV	79.2	69	86	72.6	91	107.3	65	80.2	67.5	76.4	74.4	74.9	87.6	75.5	84.7
Width	LV	54	59.3	67.1	54.7	72.3	64.9	57	58.7	58.1	50.4	52.4	59.8	65	57.3	54.5
	RV	49.9	52.7	59.4	49.4	63	61	52.1	52.1	54.5	46.1	47.6	53.5	56.7	50.2	45.1
Thickness	LV	8.3	5.5	6.7	7.5	8.4	7	5.8	3.4	6.9	5.3	6.5	6.2	5.7	9.2	6.5
	RV	5.1	4.6	5.8	6.5	6.4	9.3	5.9	5.3	6	5.5	3.6	4.9	7.1	7.1	5.1
Relaxed?		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opaque	LV	3	3	0	0.5	0	0	1	0	1	3	1	0	0	1	1
	RV	1	0	1	0	0	0	2	0	0	1	3	0	0	1	3
Transluscent	LV	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quality		3	3	3	3	2	2	3	3	3	3	2	3	2	2	3
ARV		1.25	0.75	0.25	0.125	0	0	0.75	0	0.25	1	1	0	0	0.5	1
Instrumented		Y	Y	Y				Y	Y	Y						
Comments																

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
062303_1				45		90		240								
			25,22 PSI													
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	R	R	L	L	L	L	L	L	L	L
Size		M	L	L	L	L	L	M	L	M	S	L	M	L	L	L
Height	LV	99.4	145.4	115.6	118.4	126.2	118.7	98.2	105.6	87	80.5	121	90.1	119.4	107.8	101.3
	RV	92.3	136	105.4	109.9	125.8	107	90	100	85.4	72.5	102.7	79.1	105.2	98.2	86.7
Width	LV	65.3	60.7	60	74.1	58	52.7	57.8	54	71.5	71	56.6	68.4	56.6	73.1	64.7
	RV	55.9	59.3	52	61.6	51.4	48.2	58.5	45.6	62.2	72.1	49.8	64	51.7	66.9	62.2
Thickness	LV	9.2	7.8	8.2	3.5	7.9	8.1	3.1	7.2	6.6	6.4	4.9	7.1	7.5	8.6	6.2
	RV	5.6	7.2	7.6	4.4	6.5	7.7	4.3	7.5	6.2	6.1	3.8	6.1	7.1	6.2	5.6
Relaxed?		0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Opaque	LV	3	0	0	0	3	3	1	0	3	0	2	1	1	2	0
	RV	0	2	0	0	0	1	1	0	3	0	1	1	3	3	2
Transluscent	LV	3	0	0	0	0	0	0	2	3	0	0	0	3	3	0
	RV	0	0	0	0	0	1	0	1	2	3	1	0	2	3	0
ARV		1.5	0.5	0	0	0.75	1.25	0.5	0.75	2.75	0.75	1	0.5	2.25	2.75	0.5
Quality		1	1	2	1	1	1	1.5	2	2	2	0	0	0	0.5	0
Instrumented		Y	Y	Y						Y	Y	Y				
Comments																

062303_2				52		90		240								
				27 PSI												
SIZE		L	M	M	L	M	S	S	L	L	L	M	L	S	L	M
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	R	L	L	L
Height	LV	110.9	86.2	88.7	103	94	72.3	78.4	103.7	101.3	102.9	87	117.9	65.4	102.7	90.3
	RV	96.9	77.6	79.1	96.1	89.3	72.8	78.4	96.4	85.4	89.3	79	107.2	73.1	94.6	79.8
Width	LV	67.3	67.3	52.5	61,5	65.2	56.9	51.1	74.7	57.4	68.7	52	64.1	76.5	64.6	66
	RV	63.6	63.3	46.1	54.6	60.3	51.1	47.8	64.8	54.5	51.8	47.6	54.6	69.7	54	61
Thickness	LV	9.7	5.8	5.7	4.9	6.1	4.6	5.7	6.3	6.9	7.7	5.8	7.2	5.1	5.9	6.6
	RV	4.8	5.5	4.5	6	5.7	4.9	5	5.3	6.5	7.2	5.7	7.6	3.8	6.2	6
Relaxed?		0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Opaque	LV	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0
	RV	2	0	3	0	3	0	0	2	0	3	0	3	0	2	1
Transluscent	LV	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
	RV	0	0	0	0	2	0	0	0	0	0	0	2	0	1	0
ARV		1	0	0.75	0	2.5	0	0	0.5	0	0.75	0	1.25	0	0.75	0.25
Quality		3	3	3	2	3	2	1	1	3	3	3	1	3	2	3
Instrumented		Y	Y	Y						Y	Y	Y				
Comments	Clay came off from the shell I,J,K.															

File Name		Pre-Heat	Vac	Steam		Hold		Ice											
62403		60		30		60		240											
SIZE		L	M	M	M	S	S	L	L										
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	C1	C2	C3
Banded		Y	Y	Y	Y	Y	Y	Y	Y										
Side Down		L	L	L	L	L	L	L	L										
Size		L	M	M	M	S	S	L	L										
Height	LV	109.3	93.3	85.2	96.7	80.0	82.4	103.6	103.0										
	RV	96.3	81.4	75.2	80.0	70.4	80.0	95.6	108.5										
Width	LV	61.5	75.6	58.0	50.0	54.1	55.0	55.0	65.1										
	RV	60.1	61.8	52.9	45.6	47.9	53.5	50.0	64.2										
Thickness	LV	7.7	7.6	5.1	5.5	4.9	4.9	5.4	6.6										
	RV	5.6	7.7	6.0	4.8	5.4	5.0	4.2	7.6										
Relaxed?		0.0	3.0	0.0	0.0	2.0	0.0	1.0	0.0										
Opaque	LV	0.0	0.0	3.0	0.0	0.0	0.0	2.0	2.0										
	RV	0.0	0.0	0.0	0.0	2.0	2.0	0.0	1.0										
Transluscent	LV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0										
	RV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0										
ARV		0.0	0.0	0.8	0.0	0.5	0.5	0.5	1.3										
Quality		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0										
Instrumented		Y	Y	Y															
Comments	Clay came off for A; Band broke for E.																		

File Name		Pre-Heat	Vac	Steam		Hold		Ice
062503_1		30		45		60		240
				22psi				
SIZE		S	M	S	L	M	M	M
Oyster		A	B	C	D	E	F	G
Banded		Y	Y	Y	Y	Y	Y	Y
Side Down		LV	LV	LV	LV	LV	LV	LV
Height	LV	82.2	87.6	83.6	101.6	89.4	90.7	87.3
	RV	76.1	74.8	74.0	94.9	85.5	82.4	69.6
Width	LV	62.2	63.8	54.0	62.7	63.8	65.2	55.4
	RV	55.6	57.3	58.8	62.7	57.0	61.2	54.3
Thickness	LV	8.0	4.7	6.9	7.3	5.7	3.4	3.8
	RV	6.9	4.0	7.9	5.9	5.7	4.1	4.4
Relaxed?		0.0	0.0	0.0	0.0	0.0	0.0	1.0
Opaque	LV	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RV	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Transluscent	LV	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RV	1.0	0.0	0.0	0.0	0.0	0.0	0.0
ARV		0.8	0.0	0.0	0.0	0.0	0.0	0.0
Quality		3.0	3.0	3.0	2.0	3.0	2.0	2.5
Instrumented		Y	Y	Y				
Comments								
		C1	C2	C3				
Height		75.0	130.8	78.0				
Width		47.0	65.6	66.9				
Thickness		5.3	8.9	8.9				

File Name		Pre-Heat	Vac	Steam		Hold		Ice									
062603_1	A-G	30	-8	30	17PSI	0		240									
062603_3	H-O		-8		20PSI												
SIZE		L	L	L	S	S	M	L	S	S	M	M	M	S	S	S	
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Side Down		L	L	L	L	L	L	L	L	L	L	R	R	R	R	R	
Height	LV	112.2	116.3	117.6	76.9	74.6	85.0	112.2	84.8	70.8	90.1	93.4	90.8	78.5	76.0	81.6	
	RV	104.6	111.7	105.5	81.1	70.2	78.4	100.4	72.7	68.1	79.2	84.9	85.1	75.2	68.7	69.6	
Width	LV	56.2	67.6	53.3	59.7	54.5	56.8	72.9	65.2	54.0	65.9	56.9	60.1	63.2	53.0	67.9	
	RV	50.2	60.4	51.0	56.7	53.1	51.7	78.5	66.4	51.0	61.7	53.9	54.4	61.4	52.5	61.1	
Thickness	LV	4.6	9.6	6.0	8.4	5.5	4.4	4.9	6.1	5.6	4.2	4.8	8.2	9.2	5.6	6.4	
	RV	4.8	6.0	4.5	7.1	5.7	8.4	8.2	4.7	5.3	8.0	7.2	6.2	6.8	12.9	6.3	
Relaxed?		0.0	0.0	0.0	0.0	1.0	0.0	0.0	3.0	0.0	3.0	0.0	0.0	0.0	0.0	1.0	
Opaque	LV	3.0	0.0	3.0	0.0	0.0	1.0	0.0	3.0	2.0	3.0	3.0	0.0	0.0	2.0	3.0	
	RV	3.0	0.0	3.0	3.0	0.0	2.0	0.0	0.0	1.5	3.0	0.0	0.0	3.0	1.0	1.0	
Transluscent	LV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	0.0	3.0	0.0	0.0	1.0	3.0	
	RV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	
Quality		2.0	2.0	2.0	2.5	3.0	1.0	1.0	2.5	3.0	2.5	1.0	1.0	1.0	1.0	1.0	
ARV		1.5	0.0	1.5	0.8	0.0	0.8	0.0	1.5	1.6	1.5	1.5	0.0	1.5	1.0	1.8	
Instrumented		Y	Y	Y					Y	Y	Y						
Comments	Problems with clay plugs for oysters H,I,J.																

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
63003		15		45		0		240								
				28.3												
SIZE		L	M	L	S	S	S	S	L	M	S	L	S	S	S	S
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	107.9	90	108.1	74.9	76.7	82.8	83.9	138	91.5	75	104.9	78.8	79.4	83	84.3
	RV	103.5	80.4	92.3	71.9	69.9	72.8	78	128.1	82.6	71.3	90.3	66	75.3	78.3	73.5
Width	LV	57.4	64.8	62.7	54	50	52.9	59.8	73.3	61.5	57	63	52	68.1	44.8	58.4
	RV	52.1	61.1	53	49.4	48	51.4	54.9	69.8	52	55.2	60	47.2	60.2	42.6	54.4
Thickness	LV	5.9	6	7.5	5.4	6	5.7	4.6	10.4	10.5	5.4	5	6.7	6.7	7.2	5.9
	RV	5.2	6.4	5.8	4.3	4.3	6.7	5.7	10.4	9.1	4.9	5.6	5.3	6.1	6.5	5.3
Relaxed?		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Opaque	LV	0	0	0	0	0	0	0	3	0	0	0	0	2	0	0
	RV	0	0	0	0	3	3	2	2	0	3	0	0	0	0	2
Transluscent	LV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quality		2.5	3	3	2.0	2	2	2	2	2	3	1.5	2	1.5	2	1
ARV		0	0	0	0	0.75	0.75	0.5	1.25	0	0.75	0	0	0.5	0	0.5
Instrumented		y	y	y					y	y	y					
Comments		c1	c2	c3												
Height	LV	113.4	93.3	74.6												
	RV	107.6	82.6	68.8												
Width	LV	67.1	58.6	57												
	RV	64.4	55	52.1												
Thickness	LV	9.9	5.2	6												
	RV	11.7	7.3	4.5												

IST into the muscle for oyster j and oyster K's band broke.

File Name		Pre-Heat	Vac	Steam		Hold		Ice									
70103		15		45		30		240									
				25psi													
SIZE		M	M	M	S	M	L	M	M	S	S	L	S	M	S	L	
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	
Height	LV	98.8	95.6	92.6	82.5	97.0	100.8	89.2	95.4	75.2	73.0	107.6	80.9	95.8	75.2	105.7	
	RV	86.5	88.3	85.2	79.5	95.2	91.2	75.0	91.9	69.9	63.7	96.6	75.8	90.2	74.4	93.0	
Width	LV	62.8	63.0	54.5	50.3	64.3	56.7	51.4	58.6	68.4	53.6	54.6	57.8	62.0	54.4	63.4	
	RV	58.2	56.2	53.1	45.8	58.3	56.4	48.2	58.7	59.0	50.4	52.6	57.4	55.6	53.2	61.2	
Thickness	LV	7.5	5.9	6.9	6.1	6.2	3.7	3.3	6.3	6.4	5.4	5.6	7.1	6.1	6.2	4.6	
	RV	7.5	7.9	5.9	5.7	6.4	4.5	3.3	6.2	4.8	4.4	6.4	8.1	4.9	6.0	4.8	
Relaxed?		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	2.0	
Opaque	LV	0.0	0.0	0.0	3.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	RV	0.0	3.0	3.0	0.0	0.0	0.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	3.0	
Transluscent	LV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	RV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ARV		0.0	0.8	0.8	0.8	0.0	0.8	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.8	
Quality		3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0	2.5	3.0	2.0	2.0	1.5	
Instrumented																	

Comments		C1	C2	C3	
Height		113.8	98.1	75.2	
		113.5	85.3	69.5	
Width		69.5	60.5	52.1	
		68.1	52.2	47.3	
Thickness		8.7	5.6	7.8	
		16.8	5.3	6.0	

IST into the muscle for oyster A and B.oyster O's band broke.

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
070703_1		15		30		30		240								
				15psi												
SIZE		M	M	L	S	L	S	L	M							
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y							
Side Down		L	L	L	R	L	L	L	L							
Height	LV	96	97.6	124.2	82.9	102.2	82.2	106.2	89.7							
	RV	85	84.9	107.1	76.1	82.2	79.7	100.6	84.1							
Width	LV	64.4	61.3	68.2	55.3	63	66	55.5	65.5							
	RV	59.4	59.8	62.1	55.8	55.9	63	53	62.9							
Thickness	LV	10.6	8.9	10.7	6.5	5.3	8.1	8	4.9							
	RV	7.7	7.2	8.8	7.9	5.1	6.6	5.2	6.8							
Relaxed?		0	0	0	0	0	0	0	0							
Opaque	LV	3	3	3	3	2	3	2	3							
	RV	0	3	3	3	3	3	0	3							
Transluscent	LV	3	3	3	3	3	3	3	0							
	RV	3	3	3	3	3	2	3	3							
ARV		2.25	3	3	3	2.75	2.75	2	2.25							
Quality		1.5	1	1	1	1	1	1.5	1.5							
Instrumented		Y	Y	Y												
Comments																

		c1	c2	c3
Height	LV	151.6	102.6	89.6
	RV	138.8	95	76.4
Width	LV	71	75	95
	RV	68	68.5	90
Thickness	LV	8	10	9.7
	RV	9.3	8.3	4.7

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
070703_2		15		30		45		240								
				17psi												
				19psi												
SIZE		M	L	M	L	M	M	M	L	M	M	S	S	S	S	L
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	91.3	100.9	92	107.2	88	94.8	88.2	100.6	95.1	89	83.9	77	81.2	84.5	111
	RV	83.2	91.7	76.6	97.4	73.2	89.2	83.2	86.1	87.5	80	77.3	72.8	74.1	80.5	103.7
Width	LV	61	71.9	59.2	72.1	57.7	60.7	65.2	57.4	52	60.8	65.2	61.5	53.8	60.8	77
	RV	58	63.2	51.2	71.3	53.6	58	62.1	56.7	54.1	55.2	63.4	58.1	50.9	56.6	70.4
Thickness	LV	5.4	8.2	4.6	8.2	4.6	7.7	10.3	4	8.7	6.6	5.2	4.8	4.8	6.1	6.4
	RV	4.8	6.4	5.3	8.5	5.7	6.5	6.6	4.7	9.3	8.2	5.7	5.8	4.5	6	5.7
Relaxed?		3	0	0	0	1	0	0	0	0	0	1	1	1	0	0
Opaque	LV	0	0	0	0	0	3	3	3	0	2	0	0	3	0	1
	RV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transluscent	LV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARV		0	0	0	0	0	0.75	0.75	0.75	0	0.5	0	0	0.75	0	0.25
Quality		2.5	3	3	2	1	1	1	1	2.5	3	2.5	3	3	2	1
Instrumented		Y	Y	Y						Y	Y	Y				
Comments	Band broke for L.															

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
071003_M		15		30		45		240								
				15 PSI												
SIZE		L	M	M	M	L	M	L	M							
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y							
Side Down		L	L	L	L	L	L	L	L							
Height	LV	125.4	85.4	95.6	88.4	116.5	88.4	125.7	95.8							
	RV	124.3	88.4	85	85.6	98	79.4	111.3	82.6							
Width	LV	66.4	64.1	60	71.4	61.4	70.4	70.8	71							
	RV	63	58	55.7	66.8	57.1	62.8	65.4	66							
Thickness	LV	7	9.7	7.1	7.4	5.5	5.2	5.1	7.5							
	RV	5.4	7.7	6.1	5.5	5.6	6.1	5.9	5.5							
Relaxed?		0	0	0	0	0	0	0	0							
Opaque	LV	0	3	0	0	2	0	0	2							
	RV	0	3	3	3	0	0	0	0							
Transluscent	LV	0	1	0	3	0	0	0	0							
	RV	0	0	0	0	0	0	0	0							
ARV		0	1.75	0.75	1.5	0.5	0	0	0.5							
Quality		1.5	1	2	2	1	1	1	1							
Instrumented		Y	Y	Y												
Comments																

IST into the muscle for oyster A

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
071003_A		15		30		60		240								
				14.7,15 psi												
SIZE		L	M	M	M	L	L	M	L	M	M	M	S	M	M	L
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	102.2	95.5	87.2	88.3	113	101	99.5	103	95.4	87.9	95.9	75.3	87.3	87.4	106.7
	RV	93.5	78.2	69.4	76.2	100	92.1	86.9	97.1	81.7	76.7	88	71.5	82.2	78.3	91.7
Width	LV	55.4	65	64.3	54.2	52.5	62.7	63	68.8	57.1	65.2	72.7	58.2	56.5	53	71
	RV	54.7	60.9	59.9	49.3	48.3	56.6	55.1	64.7	57.5	56.9	69.6	58	57.3	49.3	64.8
Thickness	LV	4.5	7.8	6.4	4.2	8.1	5.1	6.8	10.3	7.8	7.3	7.8	6.3	8.4	9.1	6.3
	RV	7.8	5.8	7	4.6	6.1	7.5	9.1	7.2	6.2	4.6	6.9	6.5	7.4	4.8	5.3
Relaxed?		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Opaque	LV	2	3	2	3	1	0	0	0	3	2	0	0	0	1	2
	RV	0	3	2	3	3	0	2	3	0	3	0	0	0	0	2
Transluscent	LV	0	1	0	0	2	0	0	3	3	3	1	0	0	3	3
	RV	0	0	2	0	3	0	3	3	0	0	0	0	0	0	2
ARV		0.5	1.75	1.5	1.5	2.25	0	1.25	2.25	1.5	2	0.25	0	0	1	2.25
Quality		2.5	3	3	2	1	2	1	1	1	1	1	1	1	1	1
Instrumented		Y	Y	Y						Y	Y	Y				
Comments																

		c1	c2	c3
Height	LV	107.6	100	73.2
	RV	96.9	93.2	66.5
Width	LV	70.9	57.5	51.6
	RV	60.6	54.3	50.5
Thickness	LV	7.6	6.9	9.7
	RV	6.6	6.3	6.1

File Name		Pre-Heat	Vac	Steam		Hold		Ice							
071403_M		30		30		30		240							
				18,20 PSI											

Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N
SIZE		M	M	M	L	L	S	M	S	M	M	S	S	L	M
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	98.6	94.5	86.4	106.7	111.7	82.2	85.7	83.1	88.5	93.3	81.9	80.2	152.7	85
	RV	86	91.1	77.4	91.2	102.5	81.3	78	73.6	80.6	85.6	72.6	75.6	141.1	77.6
Width	LV	53.6	70	63.3	60.9	77	49.7	49.5	66.9	64.2	60	59.5	63.7	64.9	60
	RV	45.9	67.6	59.3	58.2	68.3	44.6	46.5	60.9	58	54.8	48.5	61.3	60.5	55.9
Thickness	LV	5.9	7.5	6.8	10.8	8.8	8	4.4	6.2	6.7	5.8	8.3	5.1	4.9	5.2
	RV	6.6	6.5	5.6	7.4	8.5	6.3	5.4	4.1	6.6	6.4	6.3	5.8	8.9	5.9
Relaxed?		0	0	0	0	1	0	0	0	0	0	0	1	0	0
Opaque	LV	0	3	2	0	0	0	0	0	3	0	2	0	2	0
	RV	1	2	3	0	0	3	1	0	1	0	0	0	0	3
Transluscent	LV	0	1	0	0	0	0	0	0	3	0	2	0	0	0
	RV	0	3	3	0	0	0	0	0	0	0	0	0	3	1
ARV		0.25	2.25	2	0	0	0.75	0.25	0	1.75	0	1	0	1.25	1
Quality		3	3	3	1	1	3	2	1	3	3	3	3	1	2.5
Instrumented		Y	Y	Y						Y	Y	Y			
Comments															

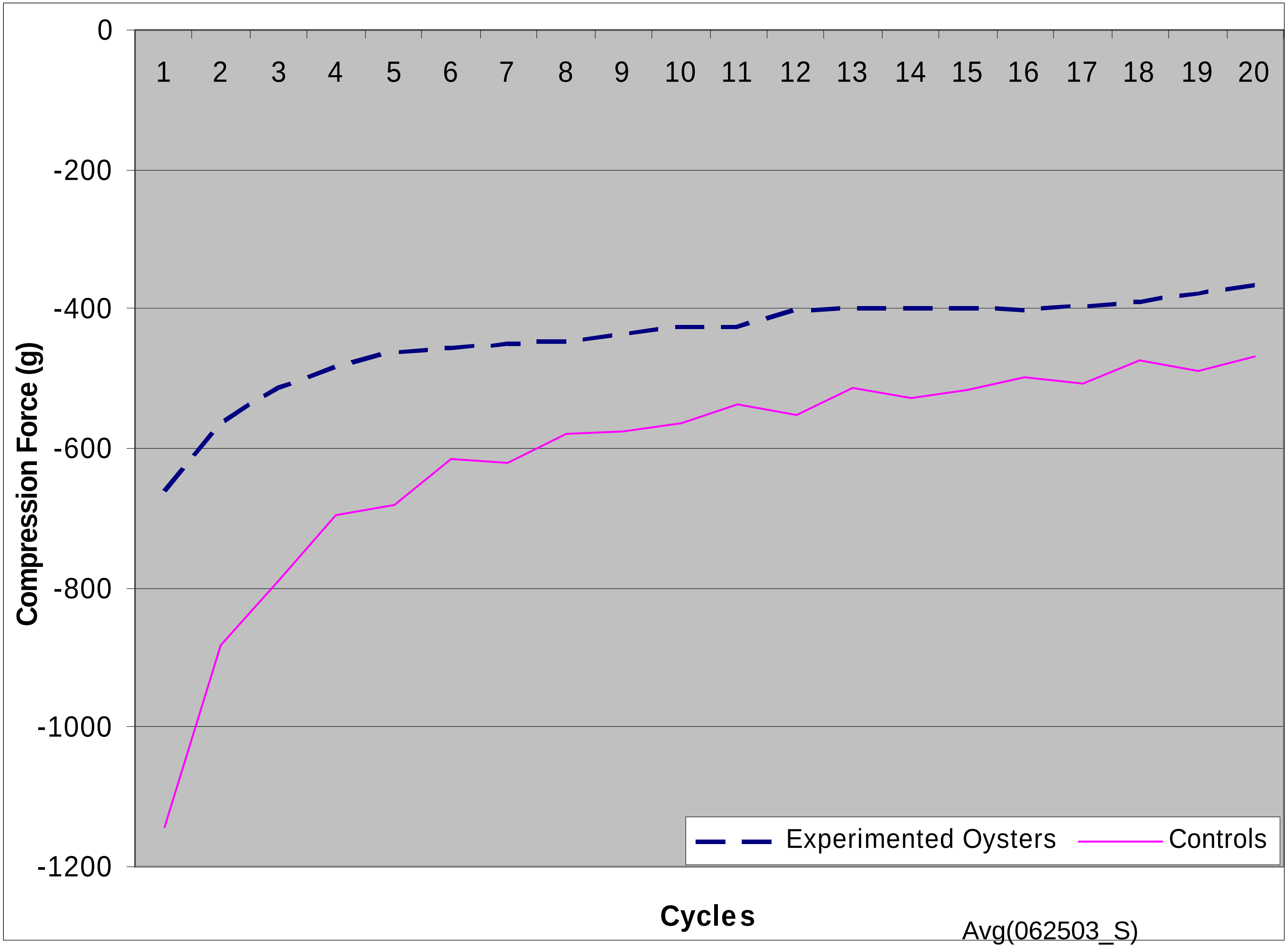
IST into the muscle for oyster A,B,J.Clay came off from the oysters I,K.

File Name		Pre-Heat	Vac	Steam		Hold		Ice								
071403_A		45		30		0		240								
Oyster		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
SIZE		L	L	S	S	S	L	S	M	S	M	M	M	S	S	S
Banded		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Side Down		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Height	LV	123.5	113	81.4	78.7	76.4	110.9	77.9	87.8	72.5	85.5	99.7	96.4	113.3	81.2	80.4
	RV	118.5	111.3	81.6	66.7	65.8	114.1	68.7	83.2	72.3	79.8	90.8	94.2	105.8	75.4	65.1
Width	LV	70.2	61.6	66.5	61.3	59.2	74.2	59.3	64.8	58.7	63.7	72	59.5	65.4	54.2	56
	RV	62.5	58.7	55.6	58.5	57.7	67.8	49.9	62.4	60.3	58.8	68.4	59.9	63.9	49.9	58.7
Thickness	LV	5.4	5.1	7.4	6.1	4.6	6.4	3.8	9.1	5.1	5.2	5.1	6.7	6.6	3.3	5.8
	RV	5	5.5	7.2	7.2	19.1	6.4	5.6	8.9	5.3	5.4	4.7	7.4	6.3	4	4.5
Relaxed?		0	0	0	0	1	0	0	0	0	0	0	0	0	3	1
Opaque	LV	3	0	0	0	3	0	0	0	0	0	3	0	0	0	0
	RV	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Transluscent	LV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARV		1	0	0	0	0.75	0	0	0	0	0	1.5	0	0	0	0
Quality		3	2	3	2	2.5	2	3	1	3	3	3	2	2	3	3
Instrumented		Y	Y	Y						Y	Y	Y				
Comments																
		c1	c2	c3												
Height	LV	110	85.9	74.1												
	RV	101.5	81.3	65.5												
Width	LV	61	56	48.3												
	RV	56.6	47.7	48												
Thickness	LV	5.4	3.9	5.1												
	RV	3.2	6.5	4												

IST into the muscle for oyster C,Jand K.

Appendix D. Compression Analysis Graphs

This appendix contains the compression analysis graphs for each of the oysters subjected to a thermal oyster shucking treatment. The maximum compression force for each of the cycles is plotted. The treated oysters are graphically compared to controls of the same size in size categories of small (left valve height, LVH, < 85.0 mm), medium (85.0 mm = LVH < 100.0 mm) and large (LVH > 100.0 mm). The size of the oysters is designated as the last character in the treatment code at the bottom right corner of each graph (S=small, M=medium, L=large).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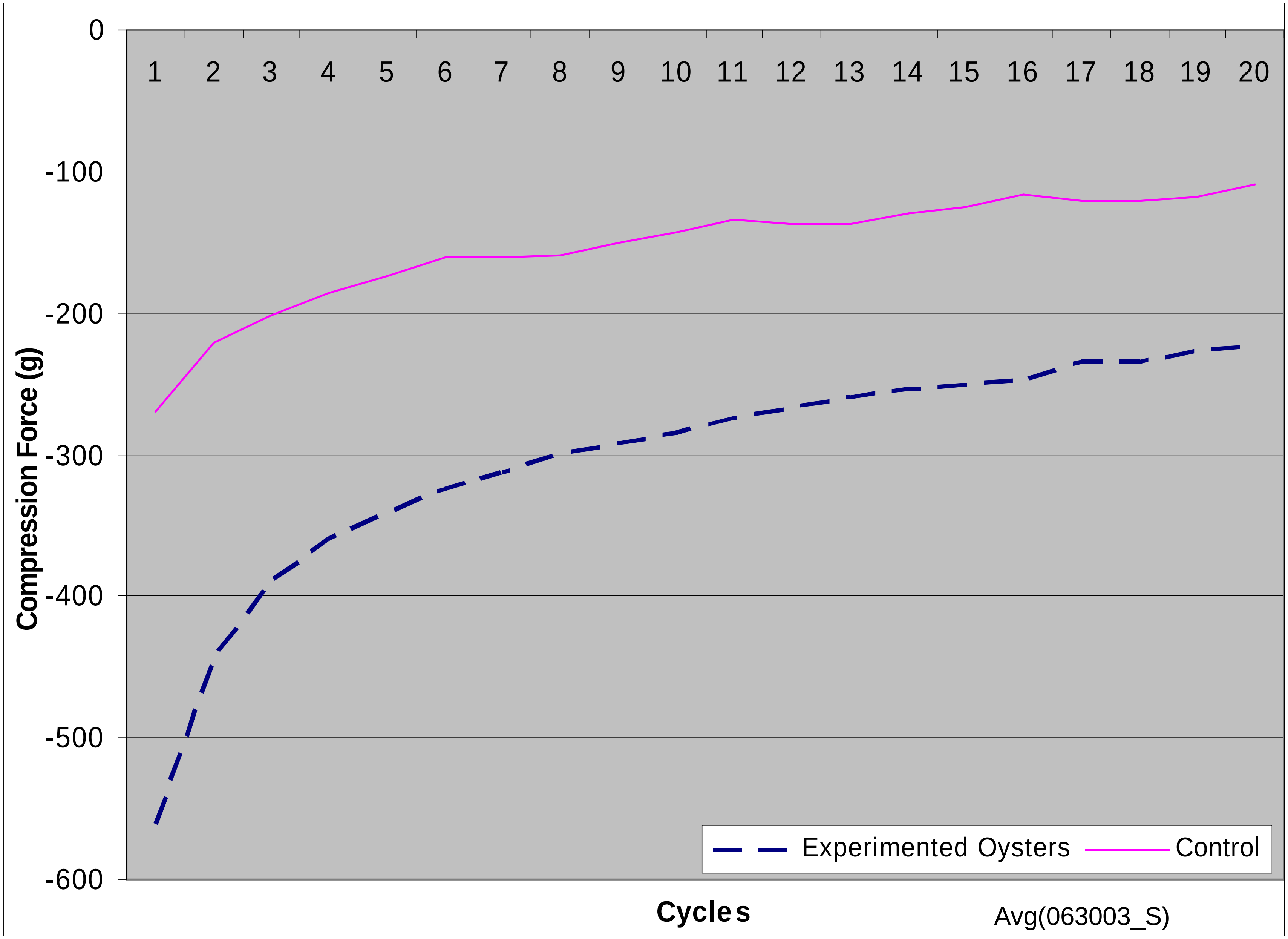
-200
-400
-600
-800
-1000
-1200
Compression Force (g)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Cycles
Experimented Oysters
Controls
Avg(062503_S)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-100
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-500
-600
Compression Force (g)
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19
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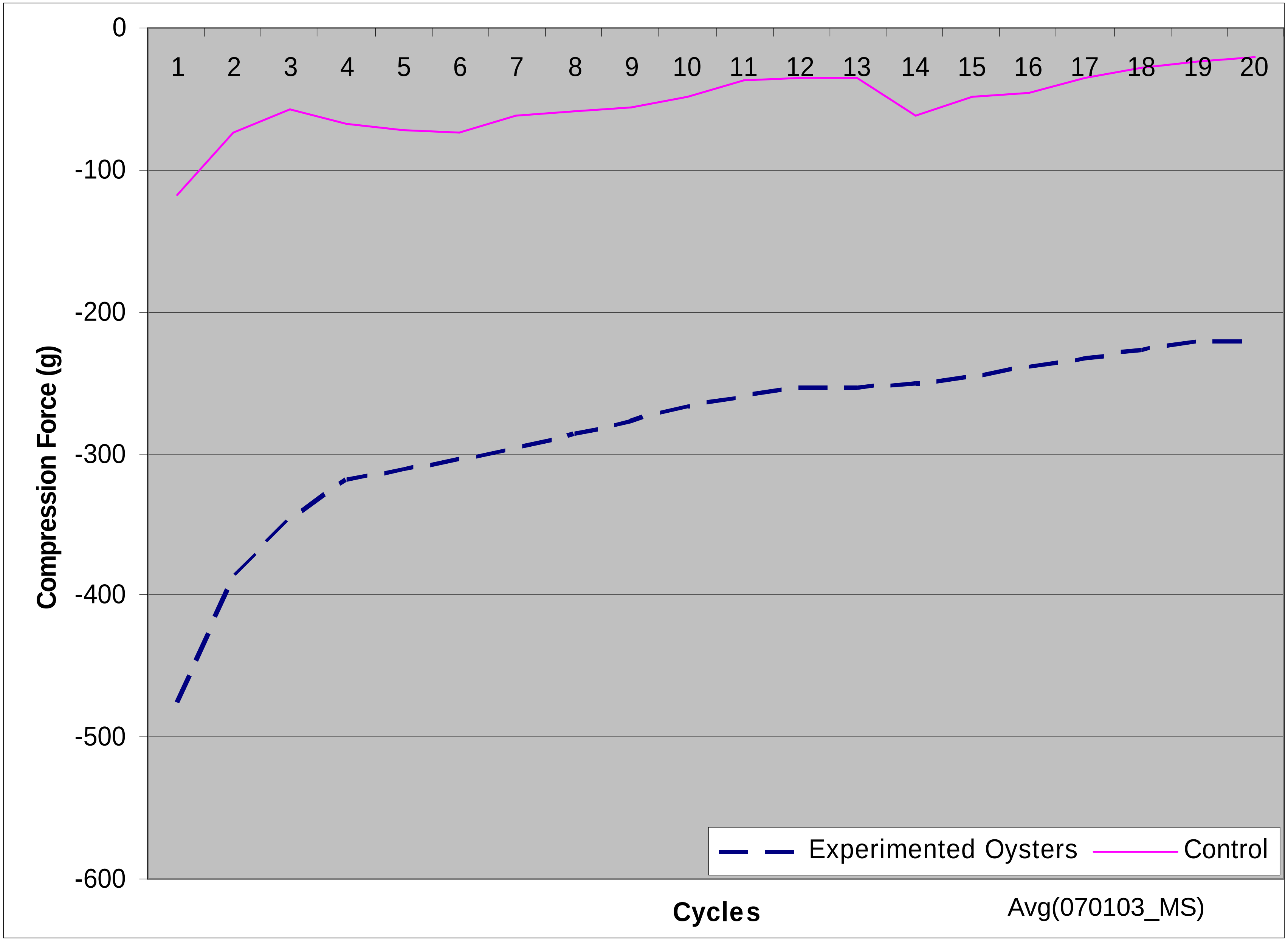
Cycles
Experimented Oysters
Control
Avg(063003_S)


0
-100
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-300
-400
-500
-600
Compression Force (g)
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19
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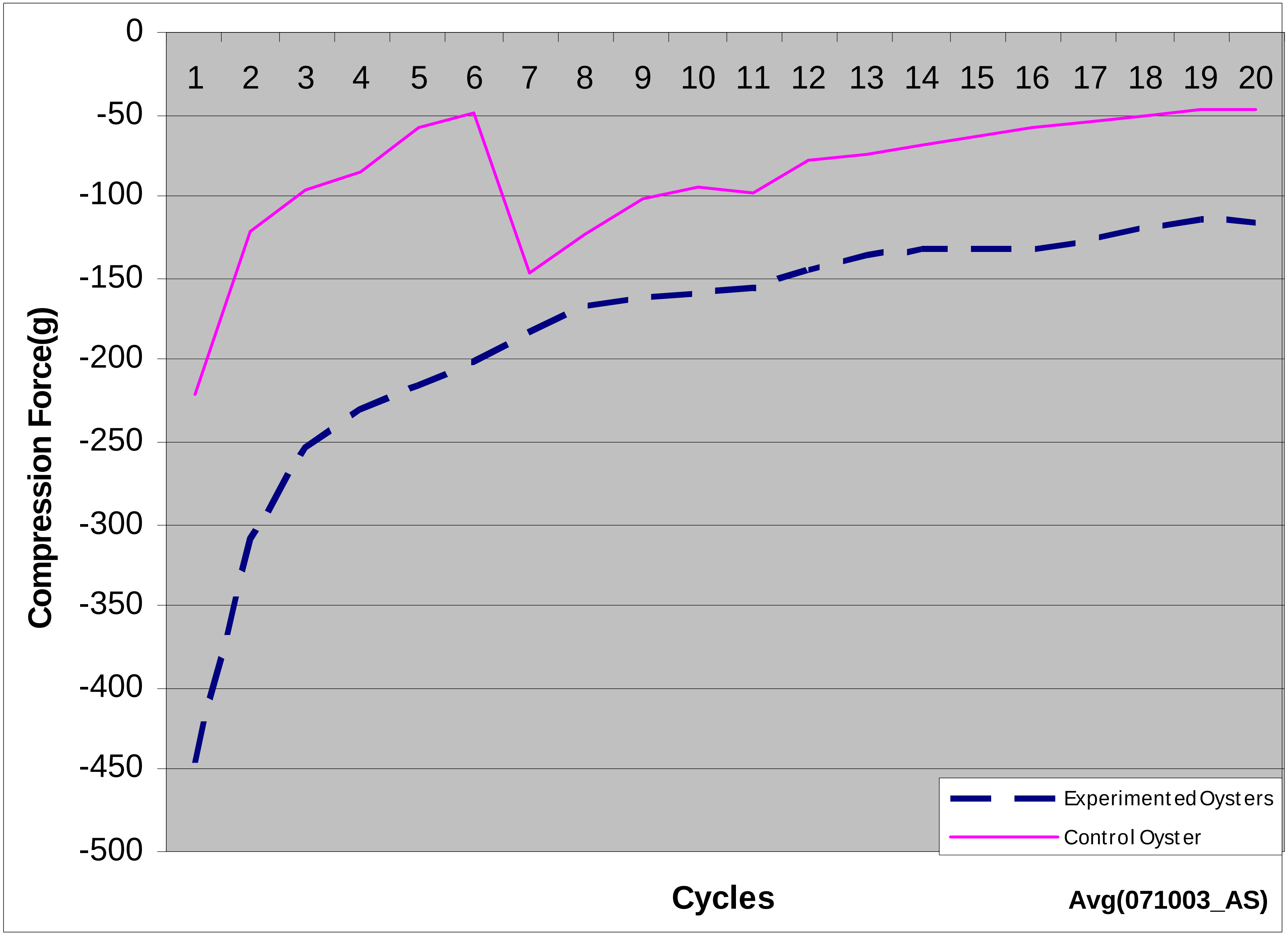
Cycles
Experimented Oysters
Control
Avg(070103_MS)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-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
Compression Force(g)
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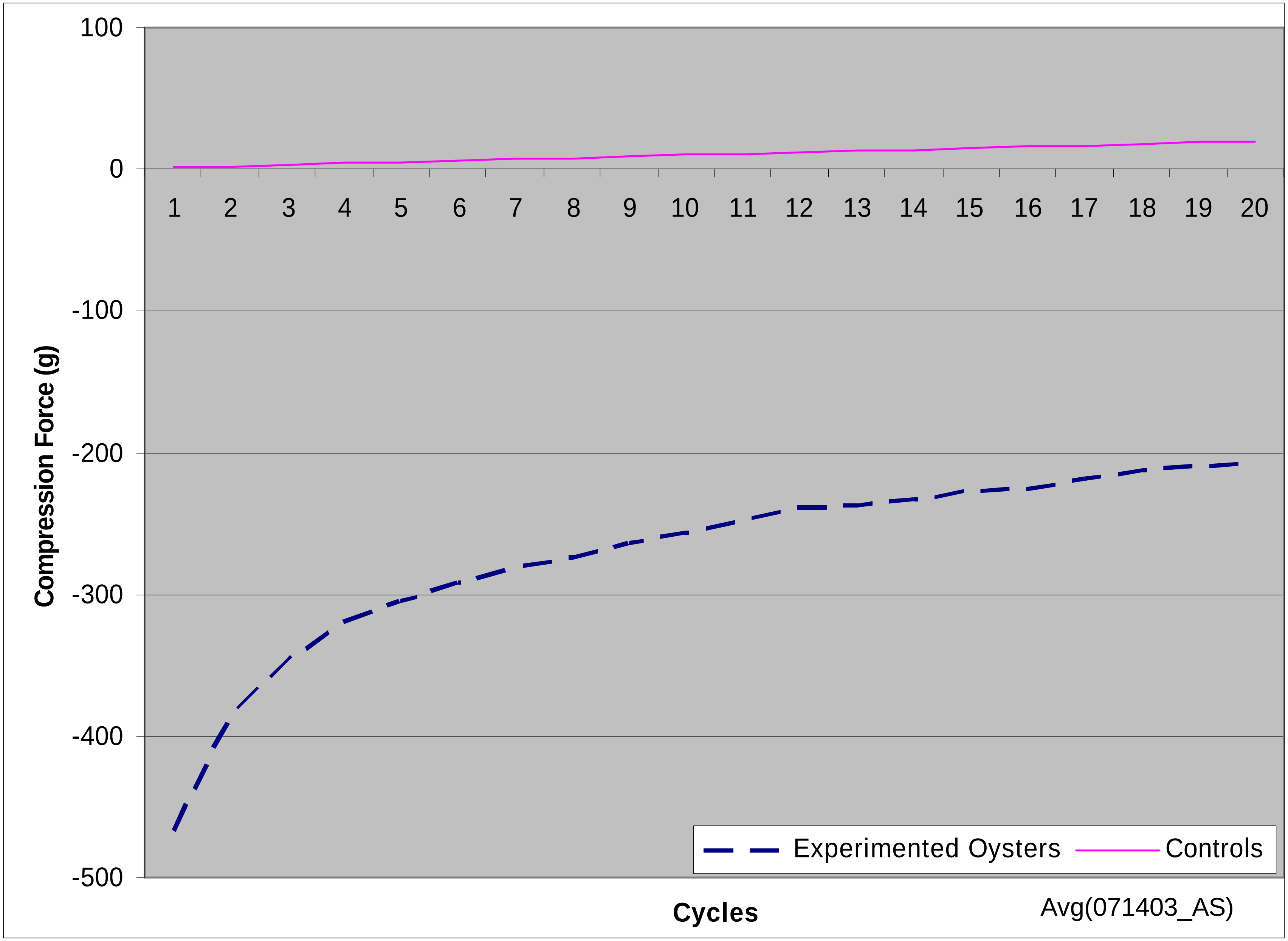
14
15
16
17
18
19
20
Cycles
Avg(071003_AS)
Experimented Oysters
Control Oyster


100
0
-100
-200
-300
-400
-500
Compression Force (g)
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16
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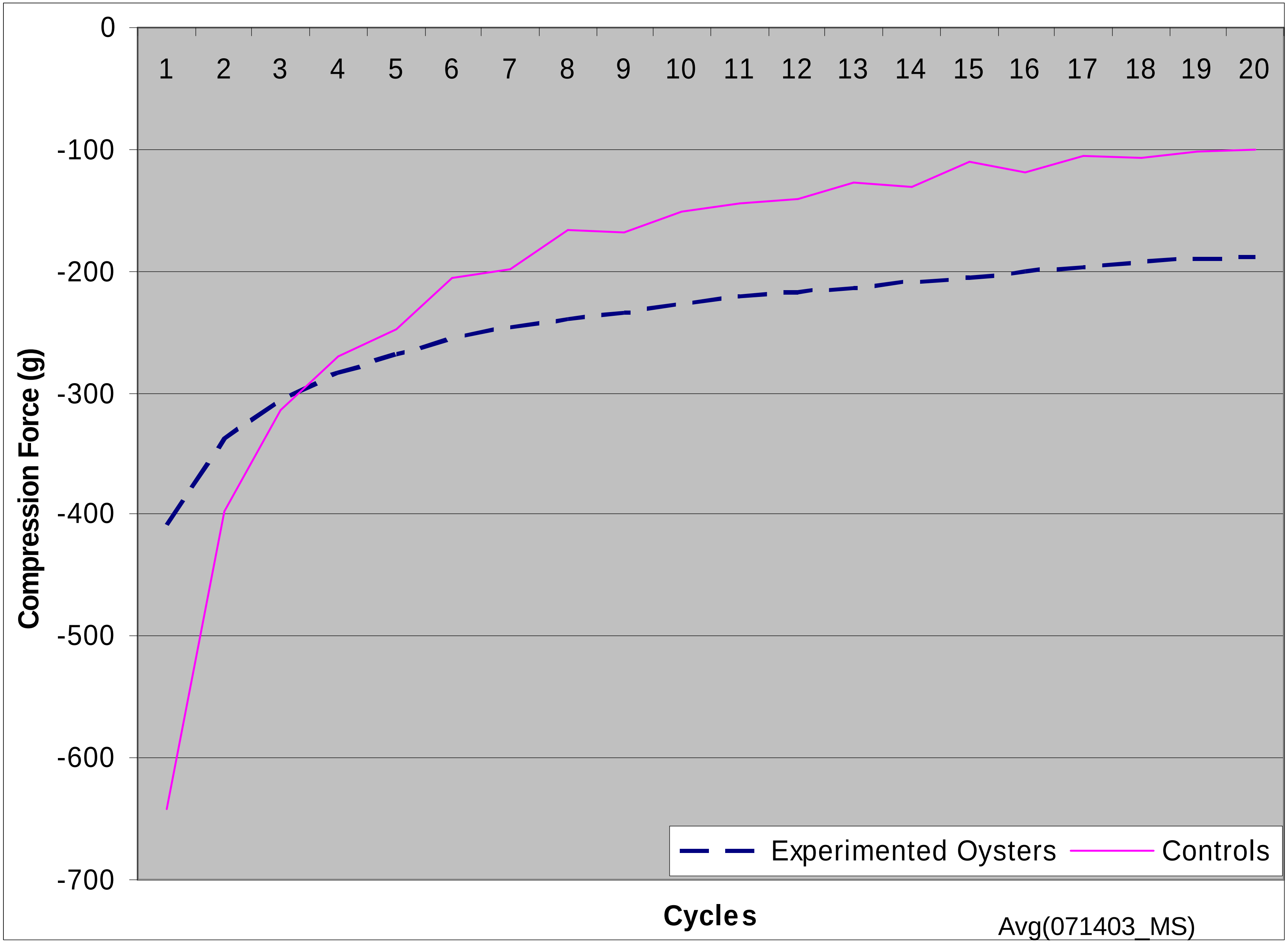
19
20
Cycles
Experimented Oysters
Controls
Avg(071403_AS)



0
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-300
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-500
-600
-700
Compression Force (g)
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19
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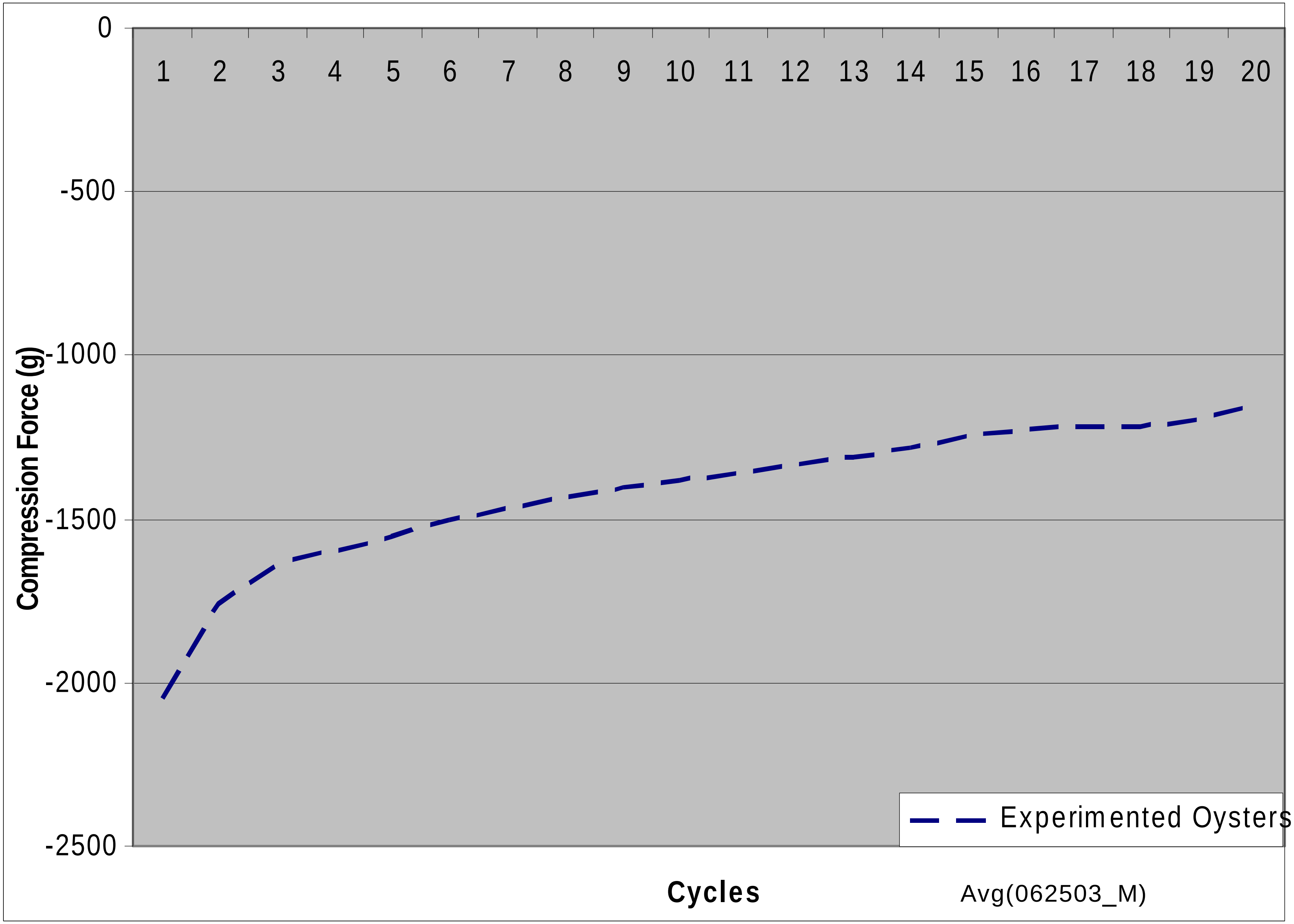
Cycles
Experimented Oysters
Controls
Avg(071403_MS)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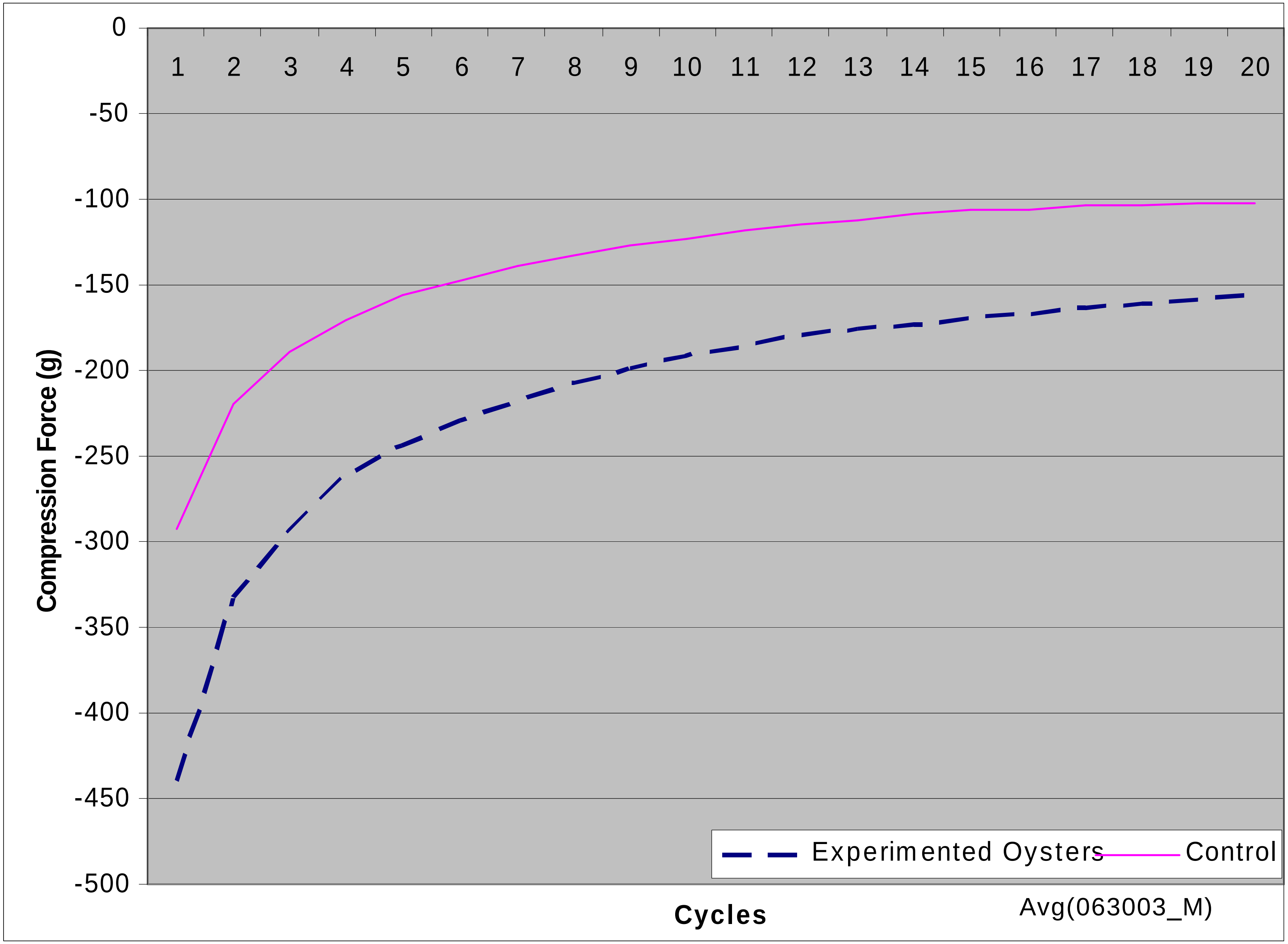
19
20
Compression Force (g)
Cycles
Experimented Oysters
Avg(062503_M)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-500
Compression Force (g)
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19
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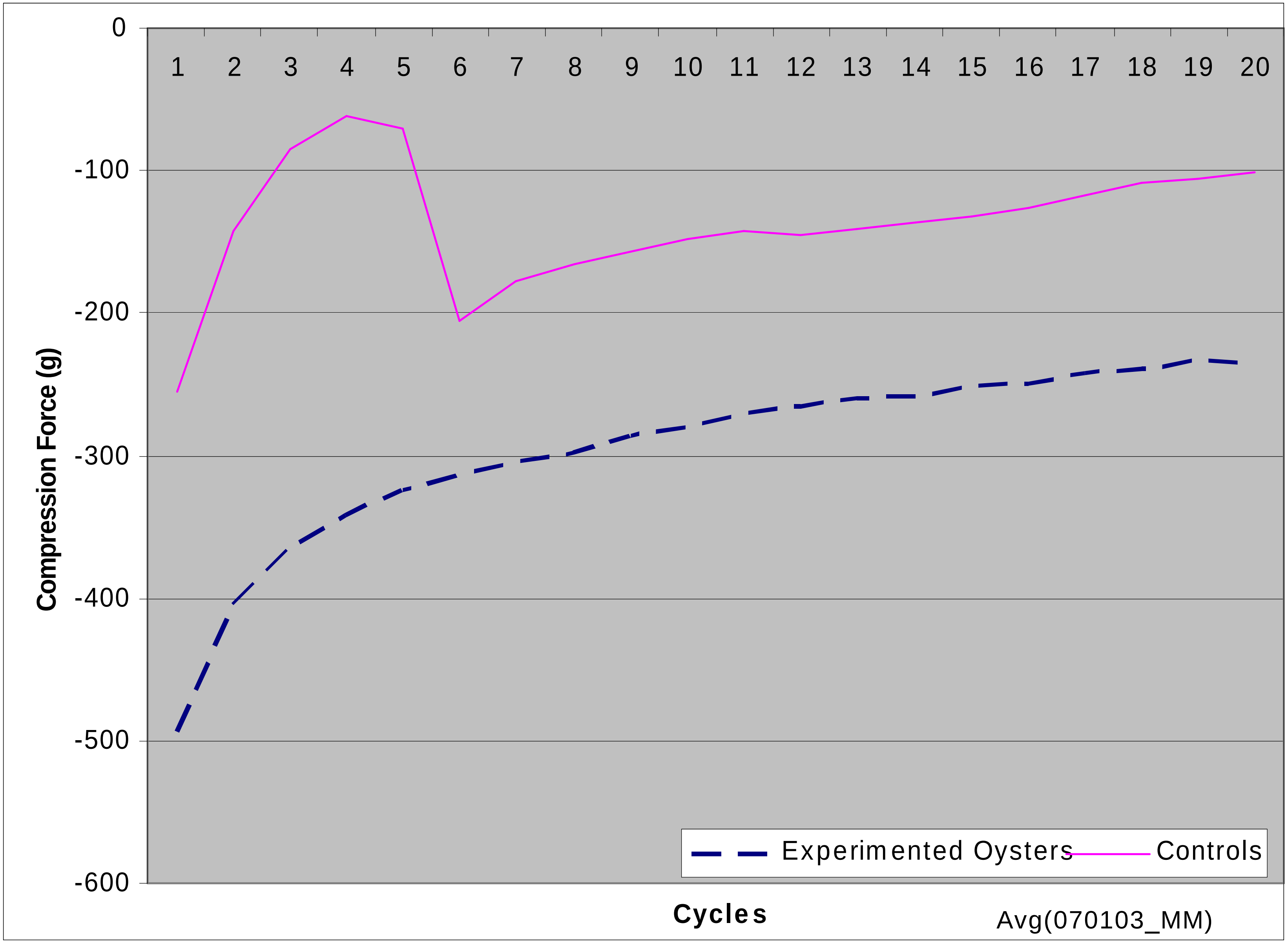
Experimented Oysters
Control
Cycles
Avg(063003_M)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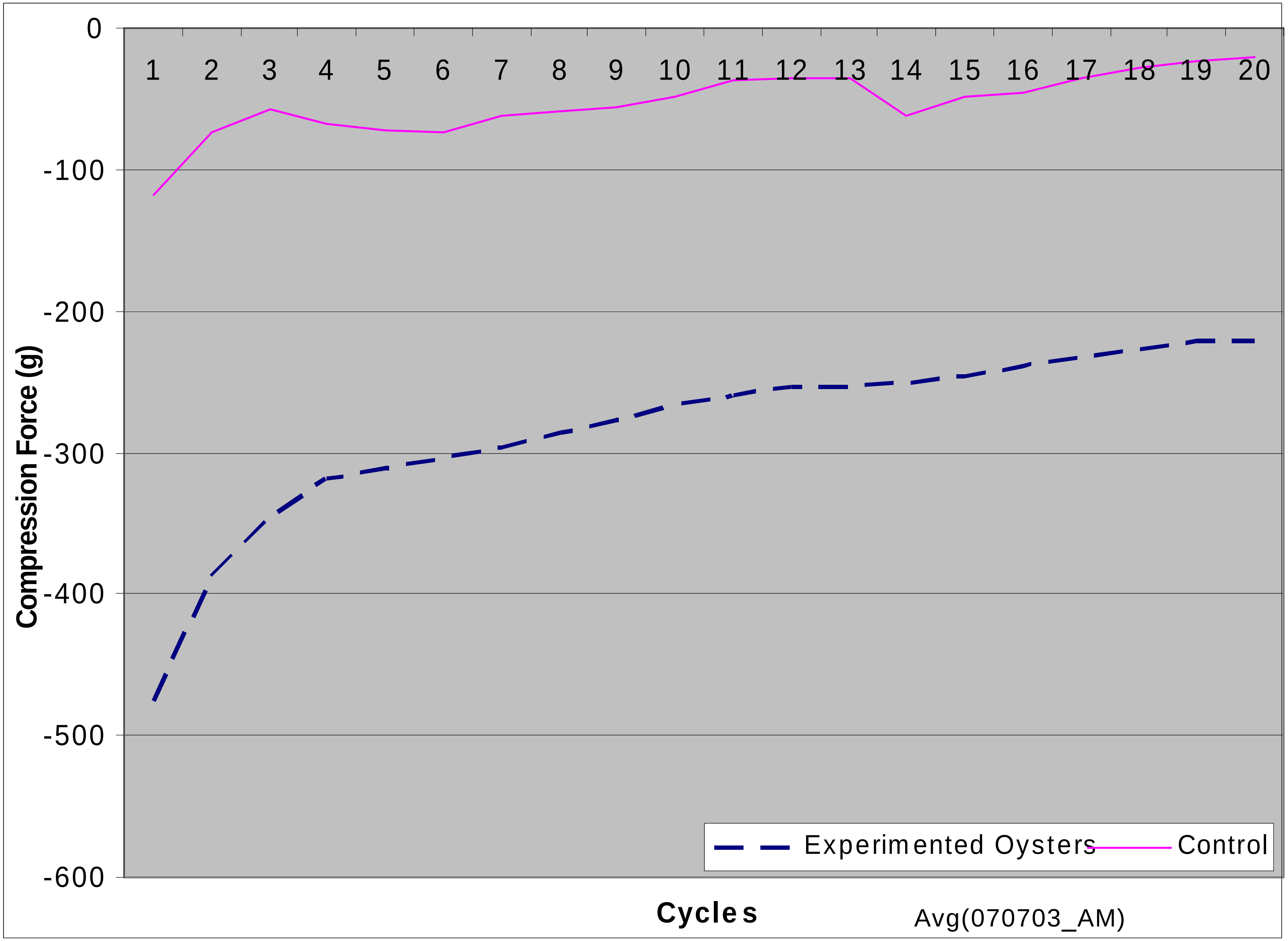
20
Compression Force (g)
Experimented Oysters
Controls
Cycles
Avg(070103_MM)


0
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-200
-300
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-500
-600
Compression Force (g)
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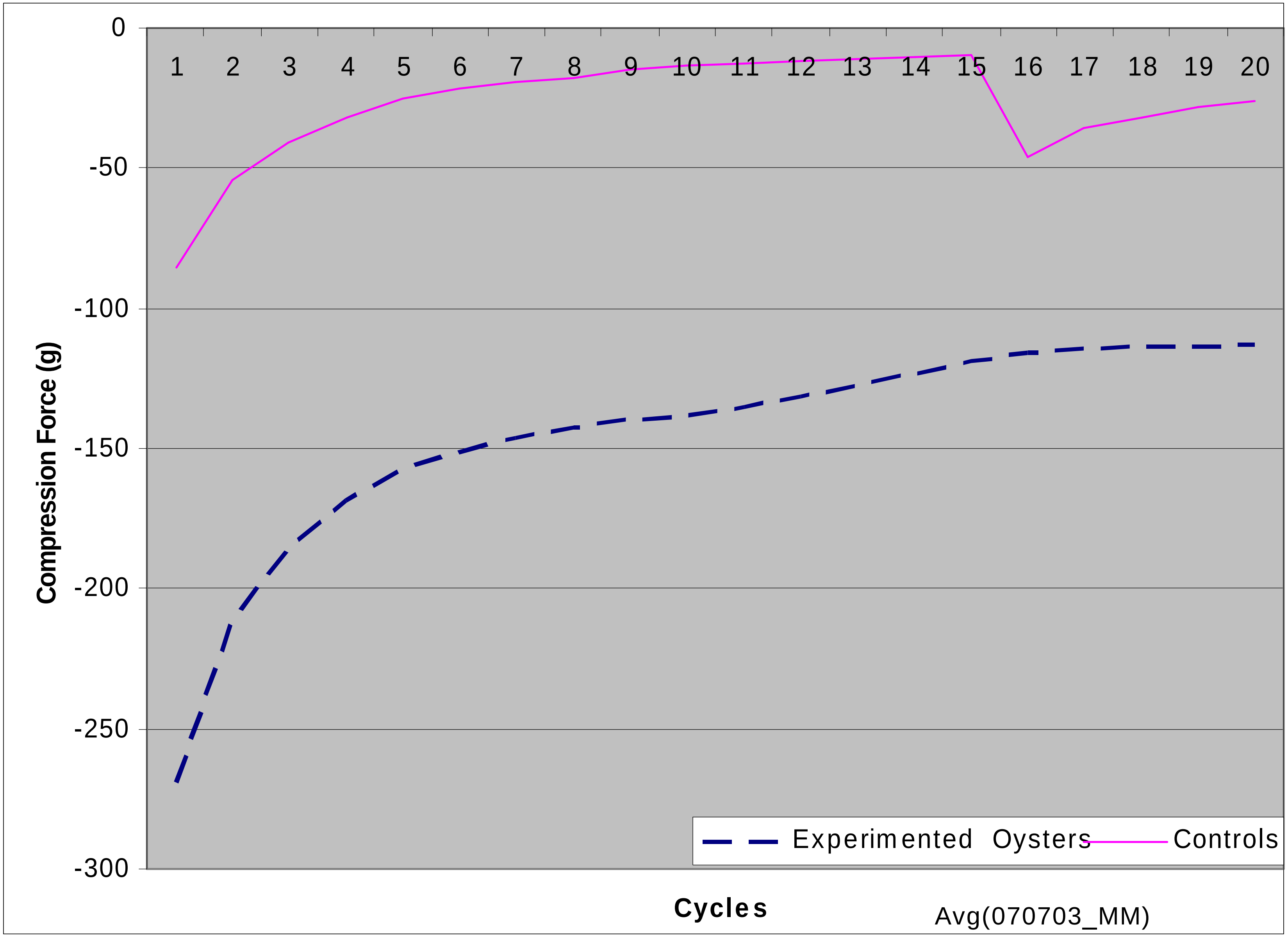
Experimented Oysters
Control
Cycles
Avg(070703_AM)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-50
-100
-150
-200
-250
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Compression Force (g)
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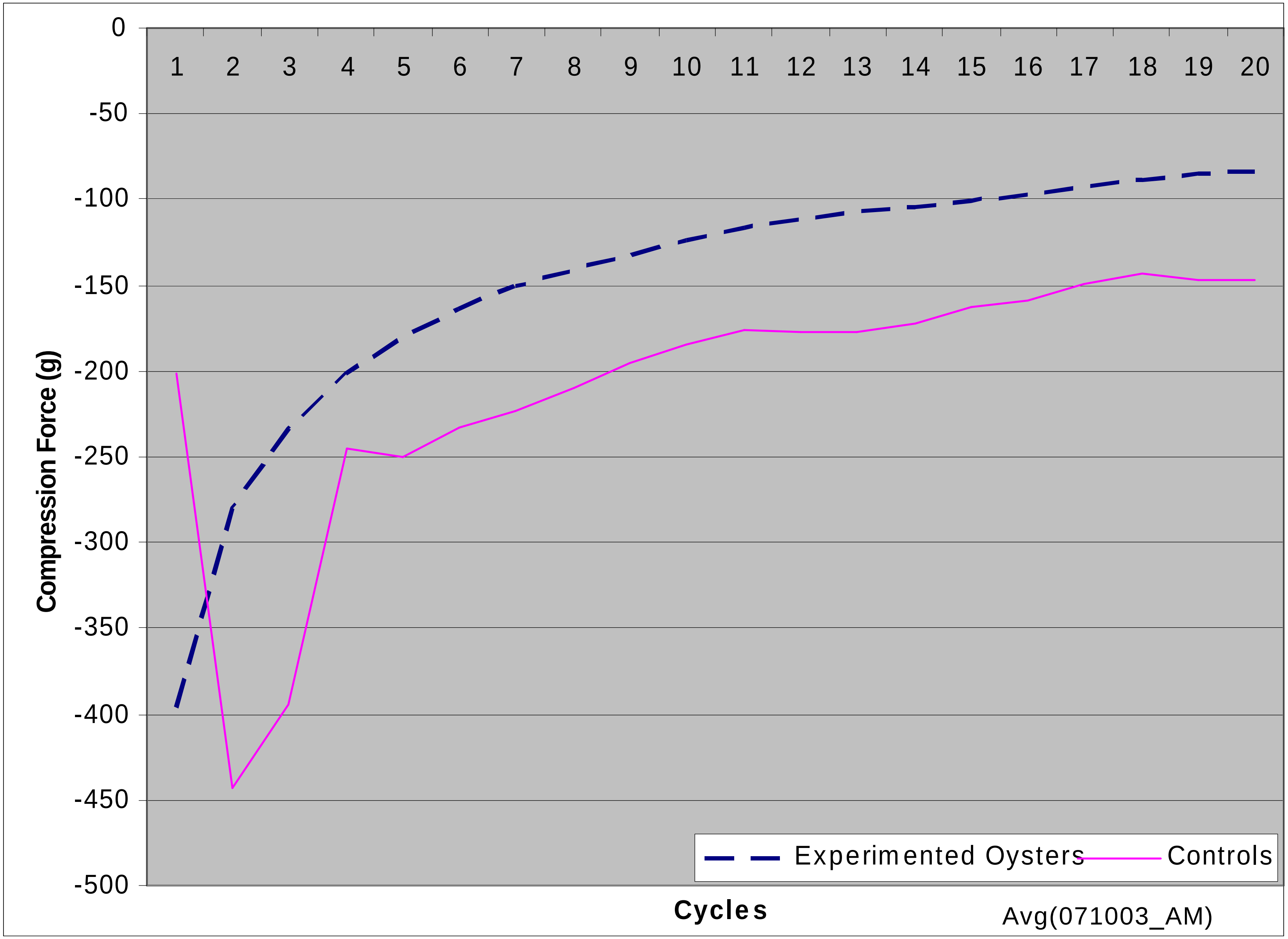
Experimented Oysters
Controls
Cycles
Avg(070703_MM)


0
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-100
-150
-200
-250
-300
-350
-400
-450
-500
Compression Force (g)
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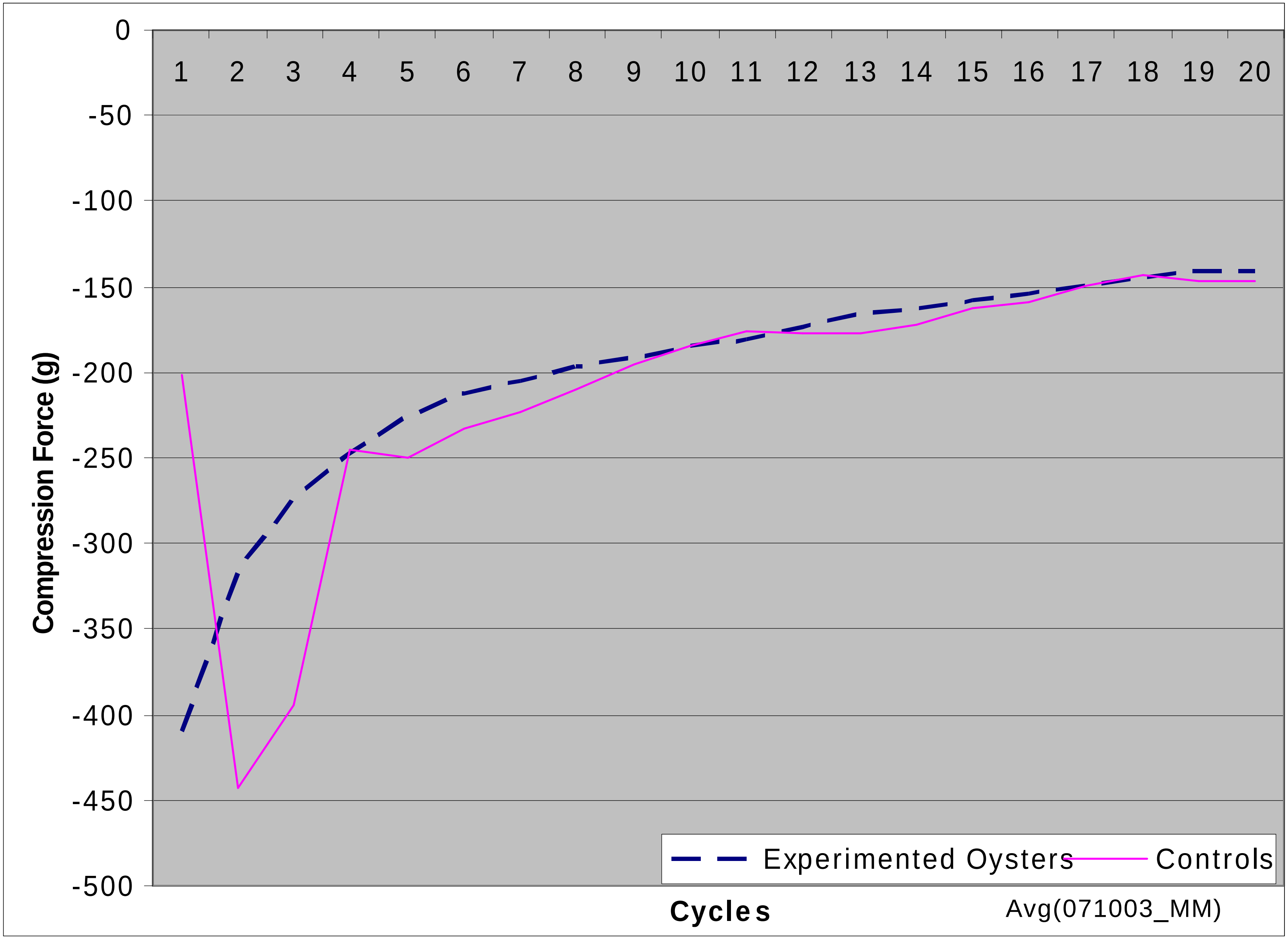
Cycles
Experimented Oysters
Controls
Avg(071003_AM)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-500
Compression Force (g)
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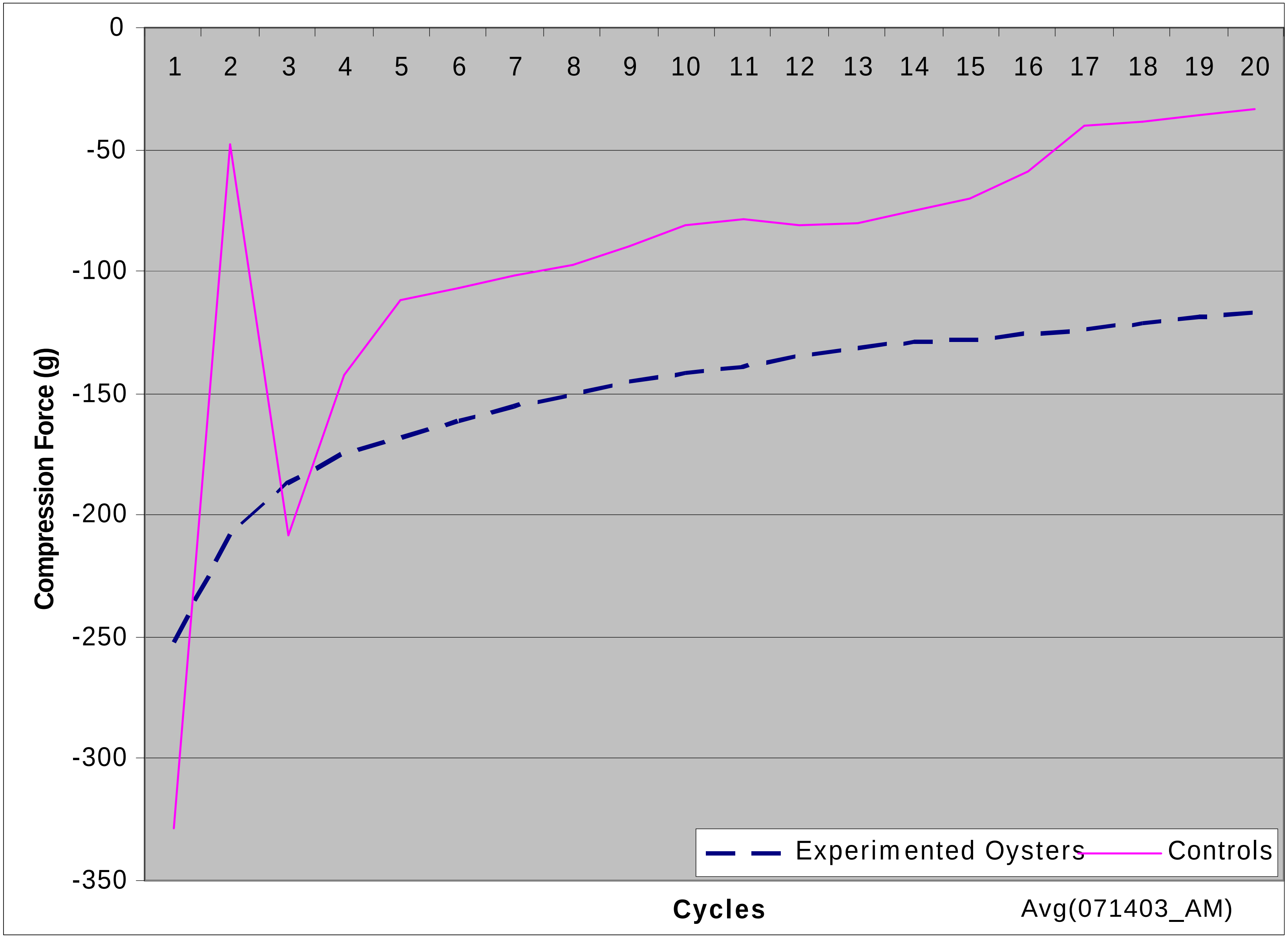
Experimented Oysters
Controls
Cycles
Avg(071003_MM)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Compression Force (g)
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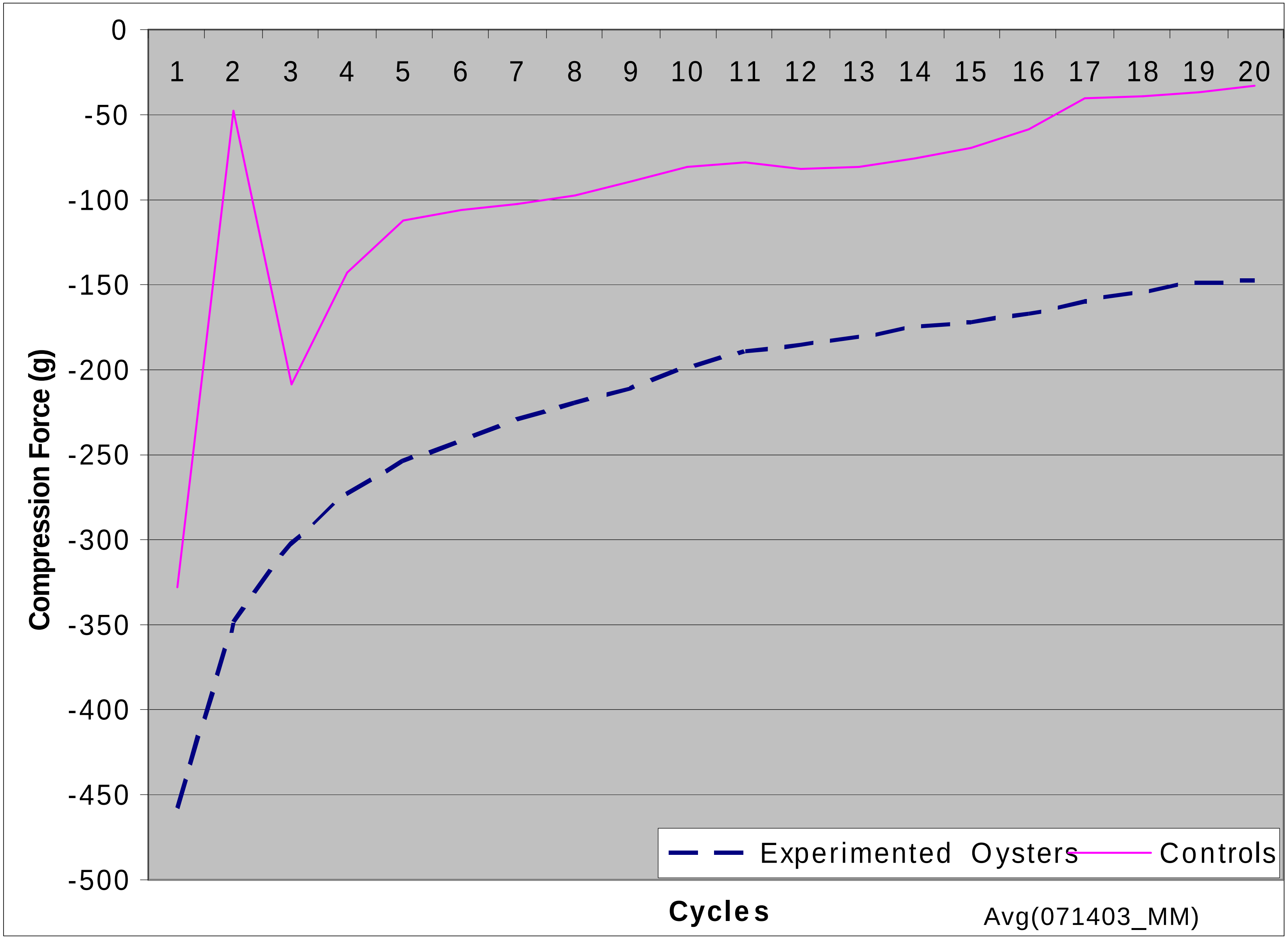
Experimented Oysters
Controls
Cycles
Avg(071403_AM)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Compression Force (g)
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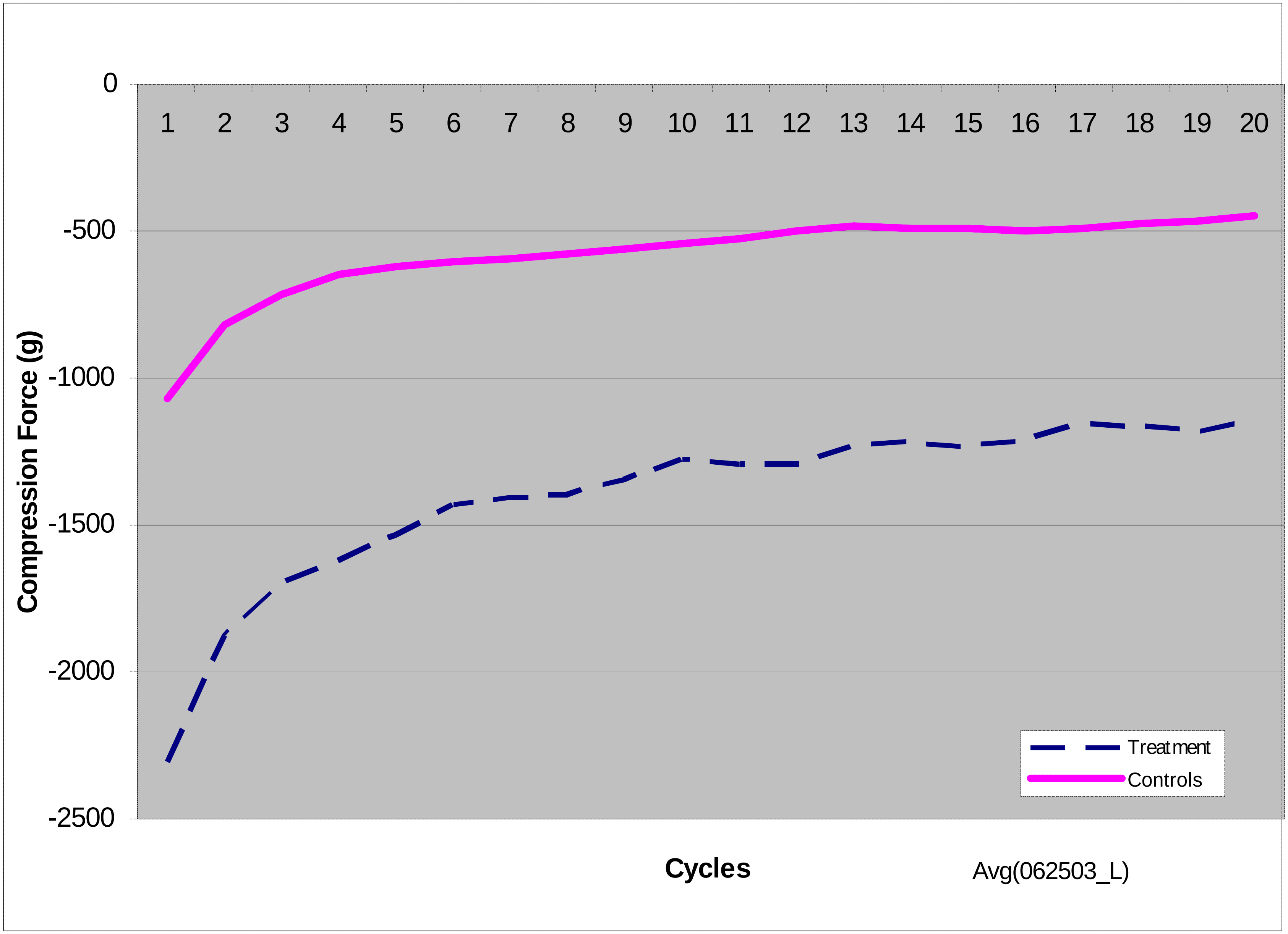
Experimented Oysters
Controls
Cycles
Avg(071403_MM)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Compression Force (g)
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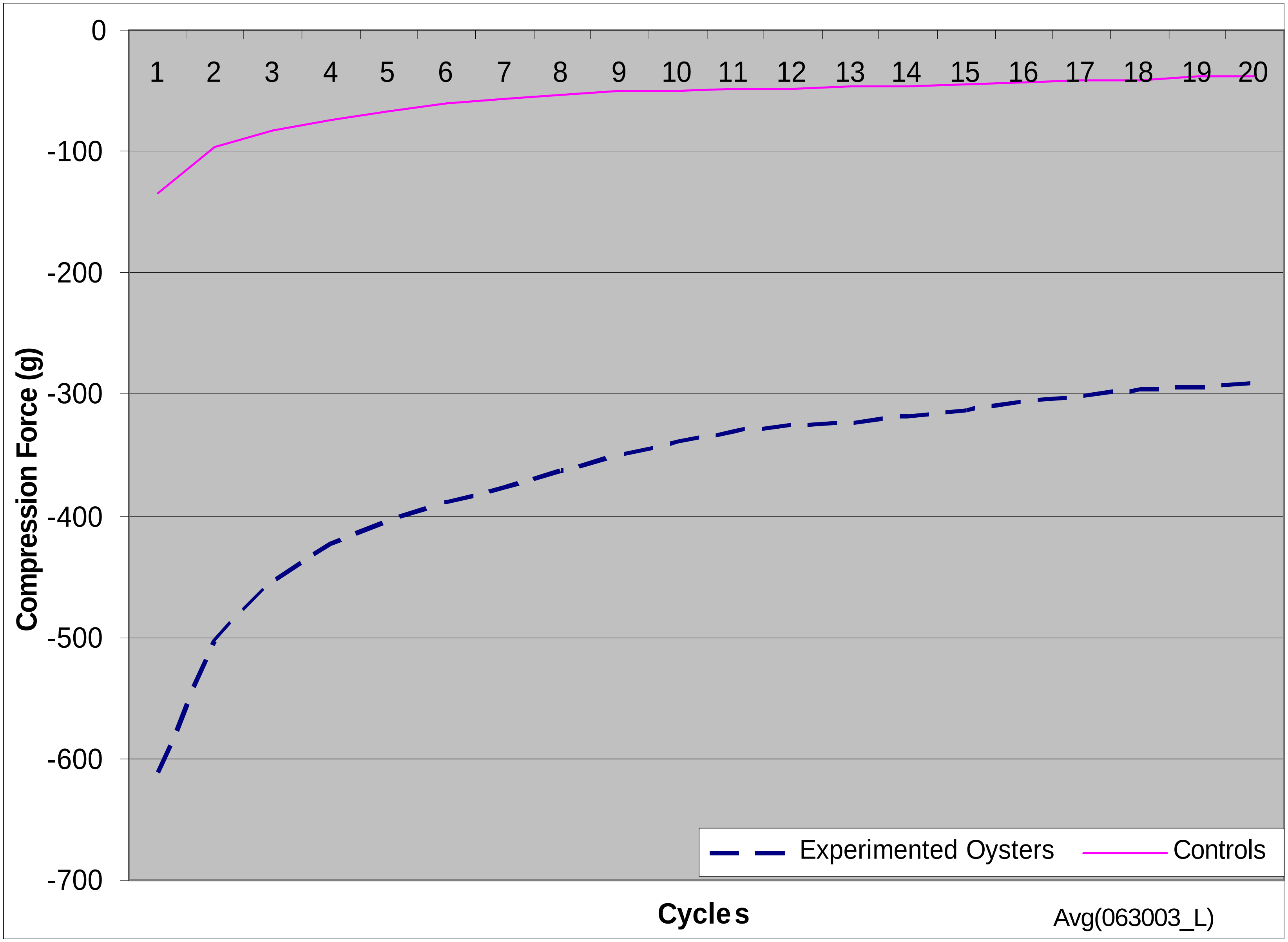
Treatment
Controls
Cycles
Avg(062503_L)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19
20
Compression Force (g)
Cycles
Experimented Oysters
Controls
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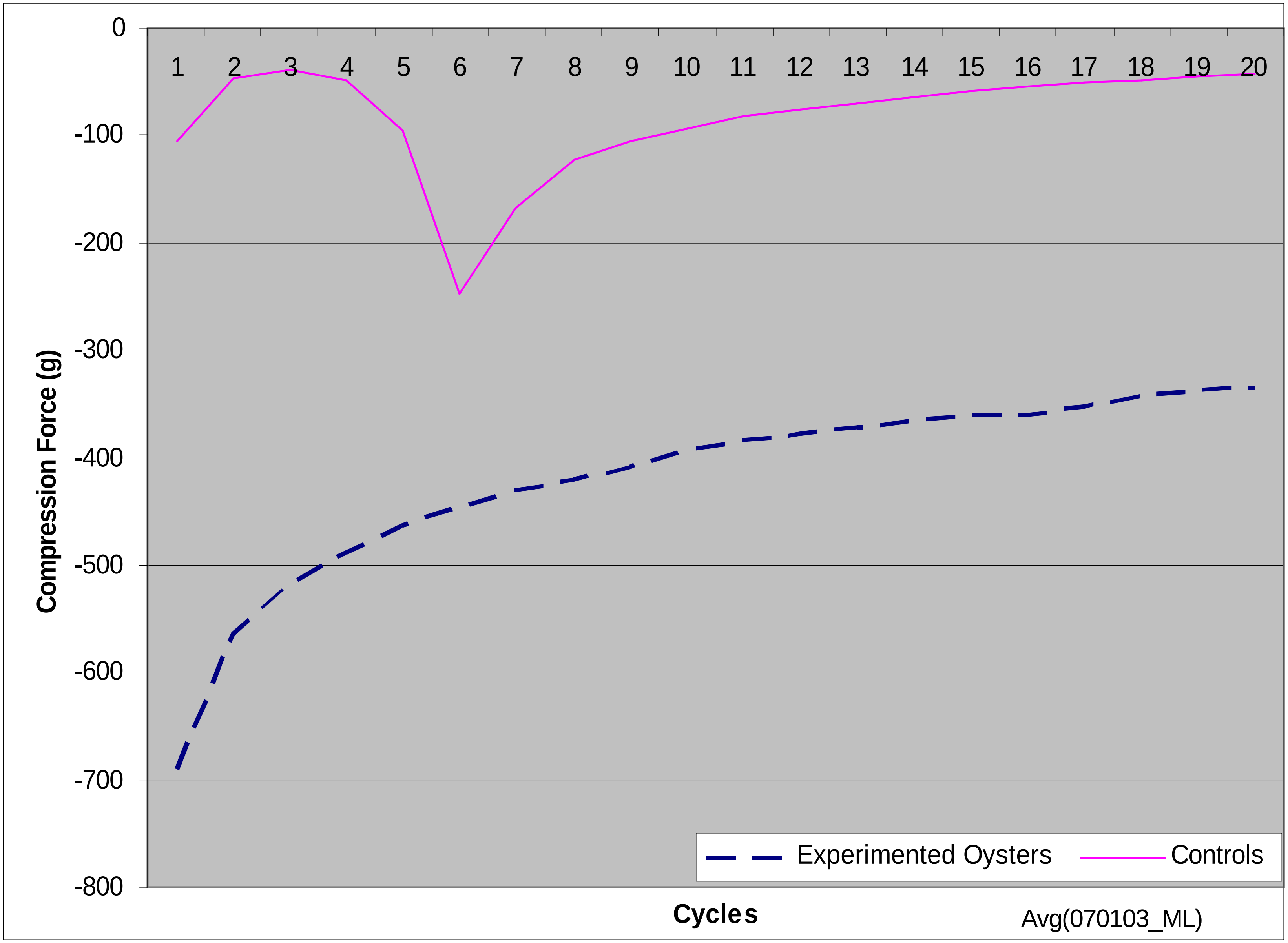
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-800
Compression Force (g)
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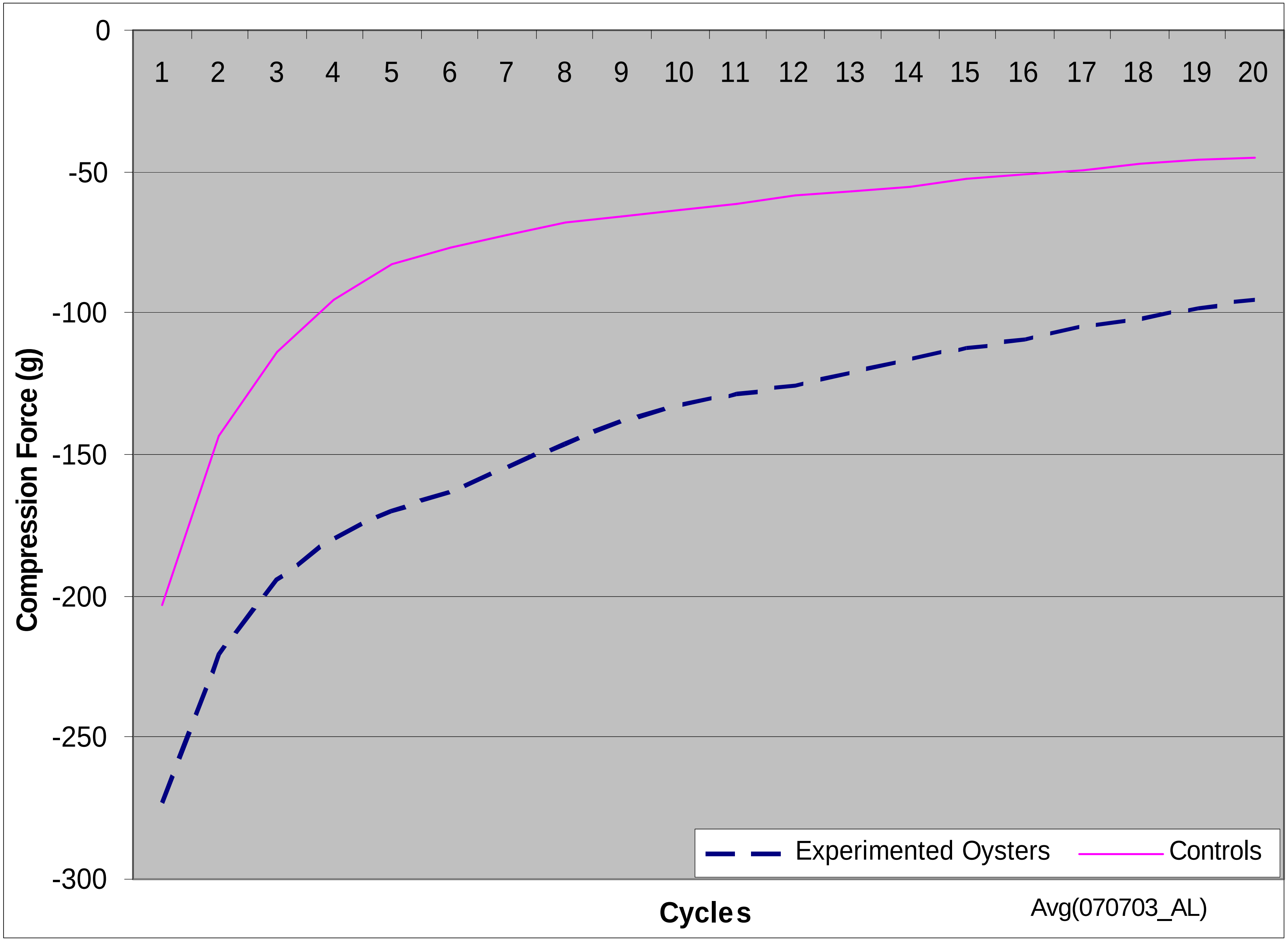
Experimented Oysters
Controls
Cycles
Avg(070103_ML)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-300
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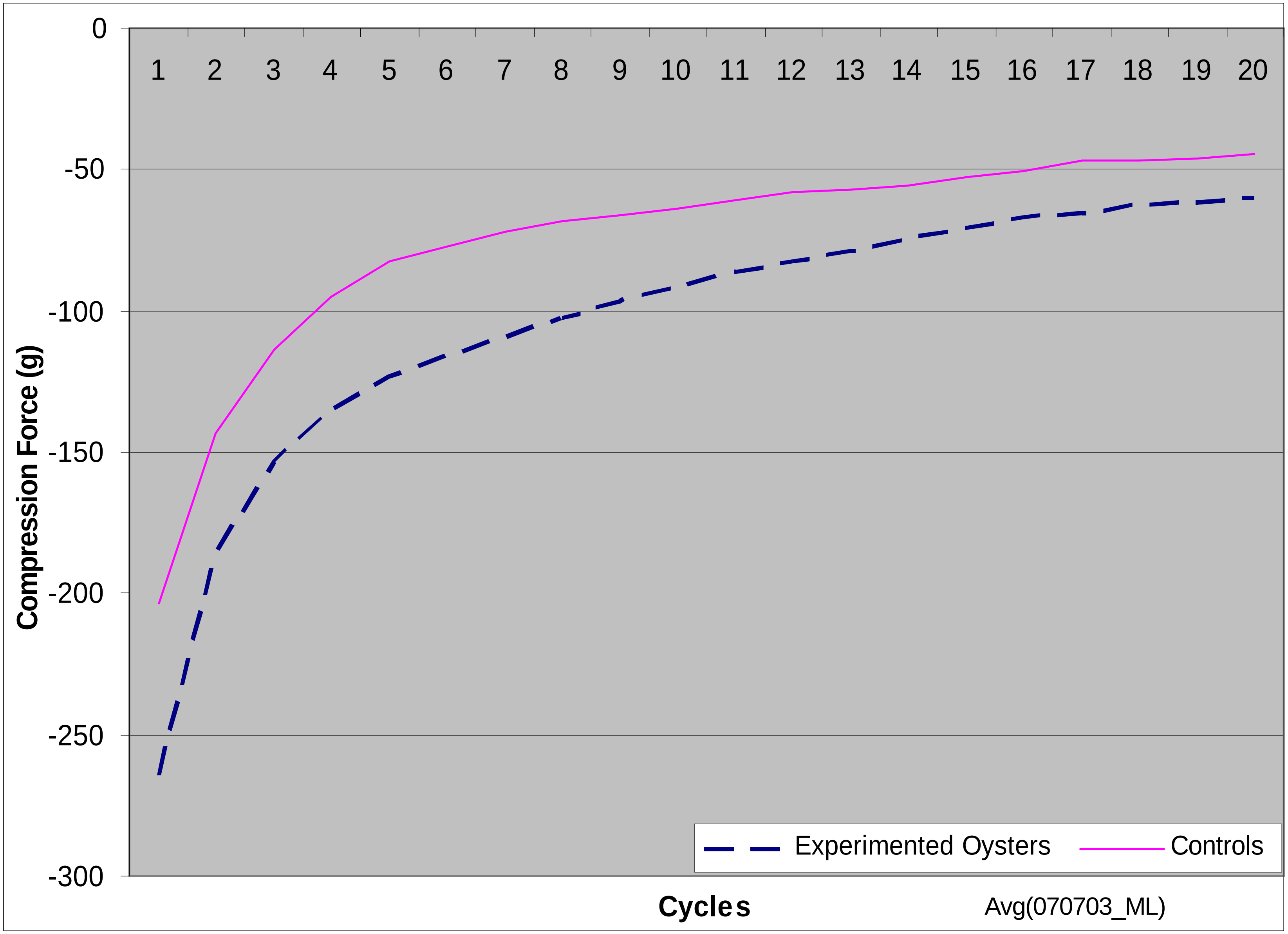
Experimented Oysters
Controls
Cycles
Avg(070703_AL)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Compression Force (g)
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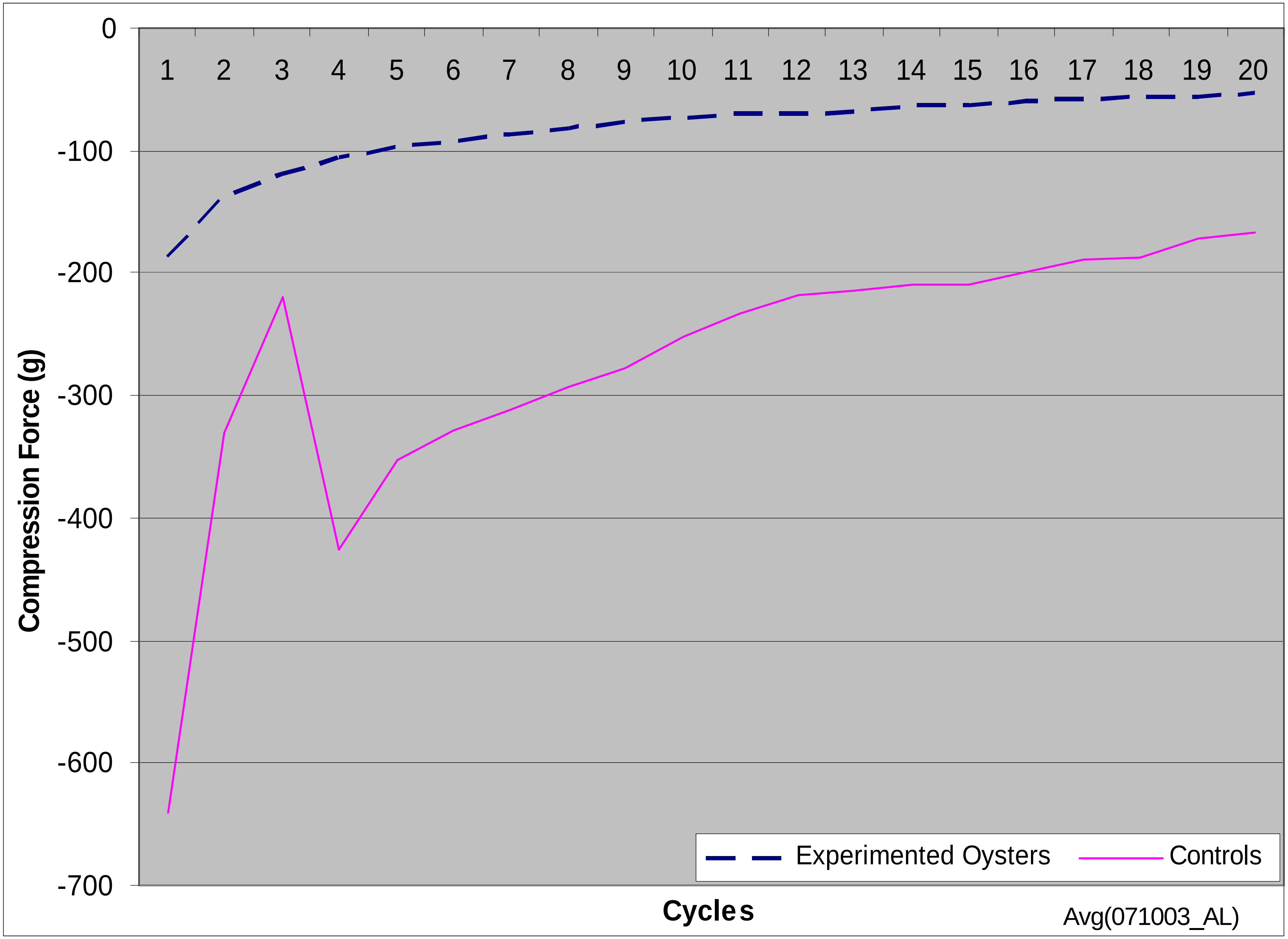
Experimented Oysters
Controls
Cycles
Avg(070703_ML)



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-400
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-600
-700
Compression Force (g)
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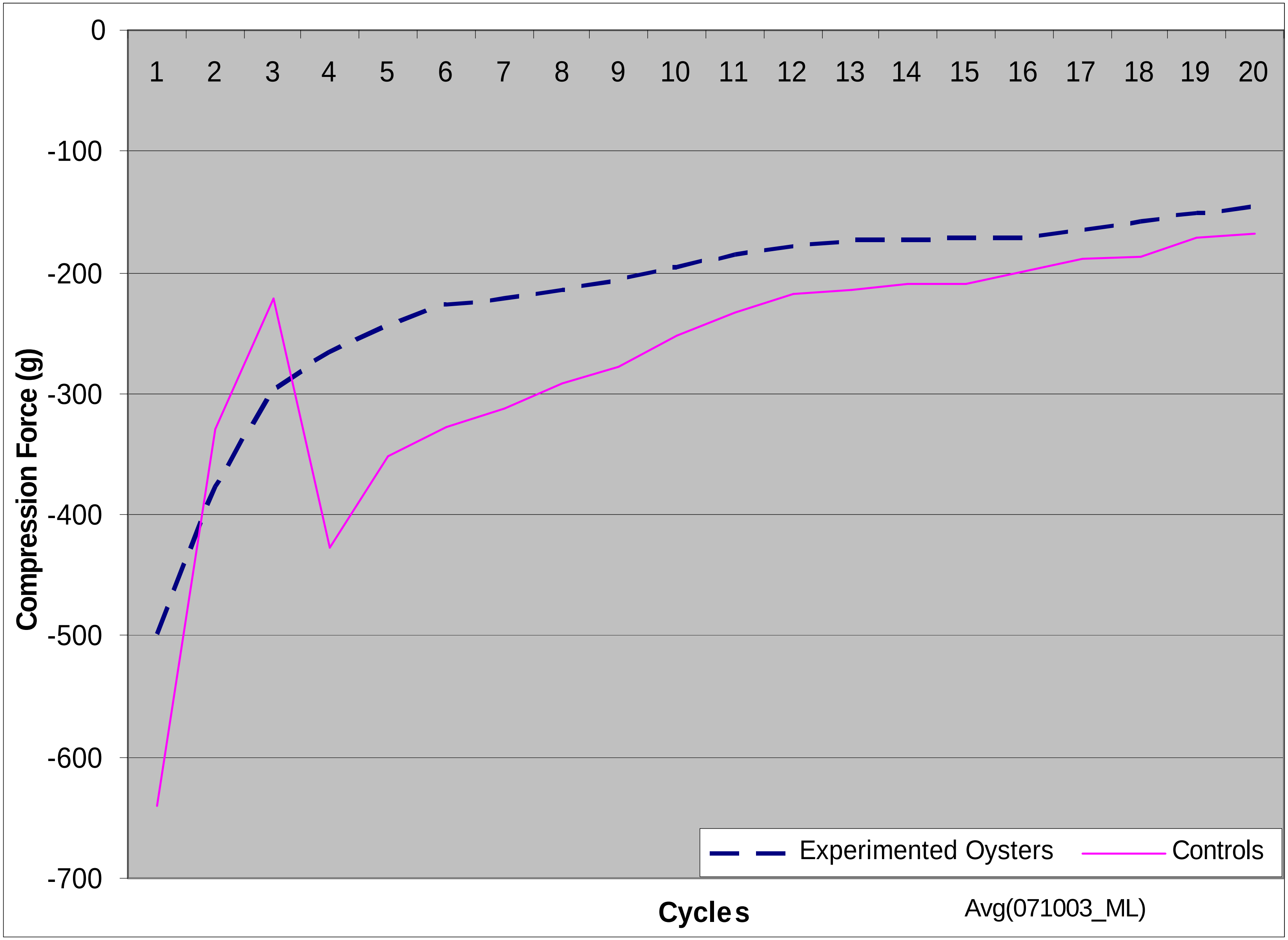
Experimented Oysters
Controls
Cycles
Avg(071003_AL)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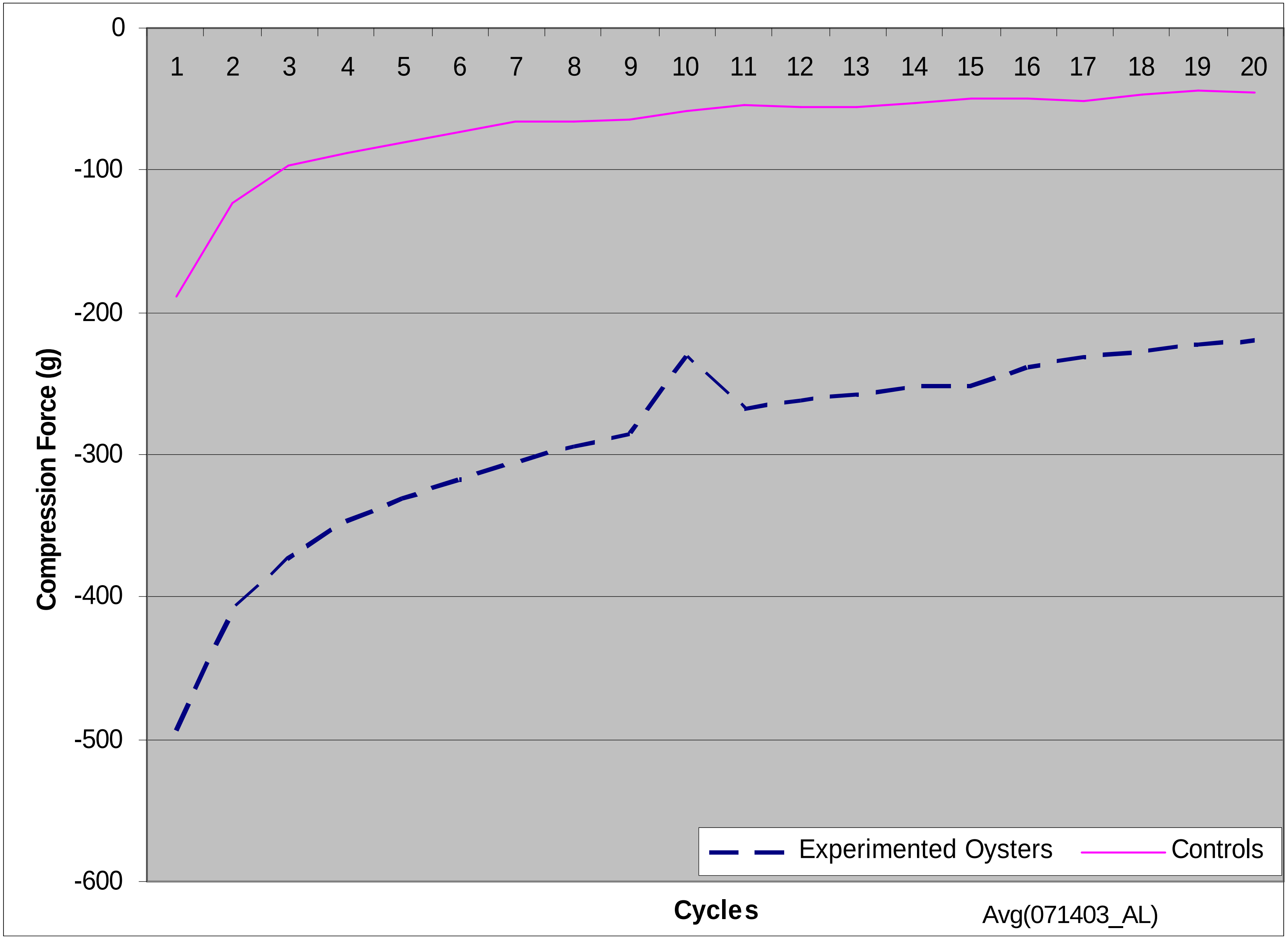
19
20
Compression Force (g)
Cycles
Avg(071003_ML)
Experimented Oysters
Controls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-600
Compression Force (g)
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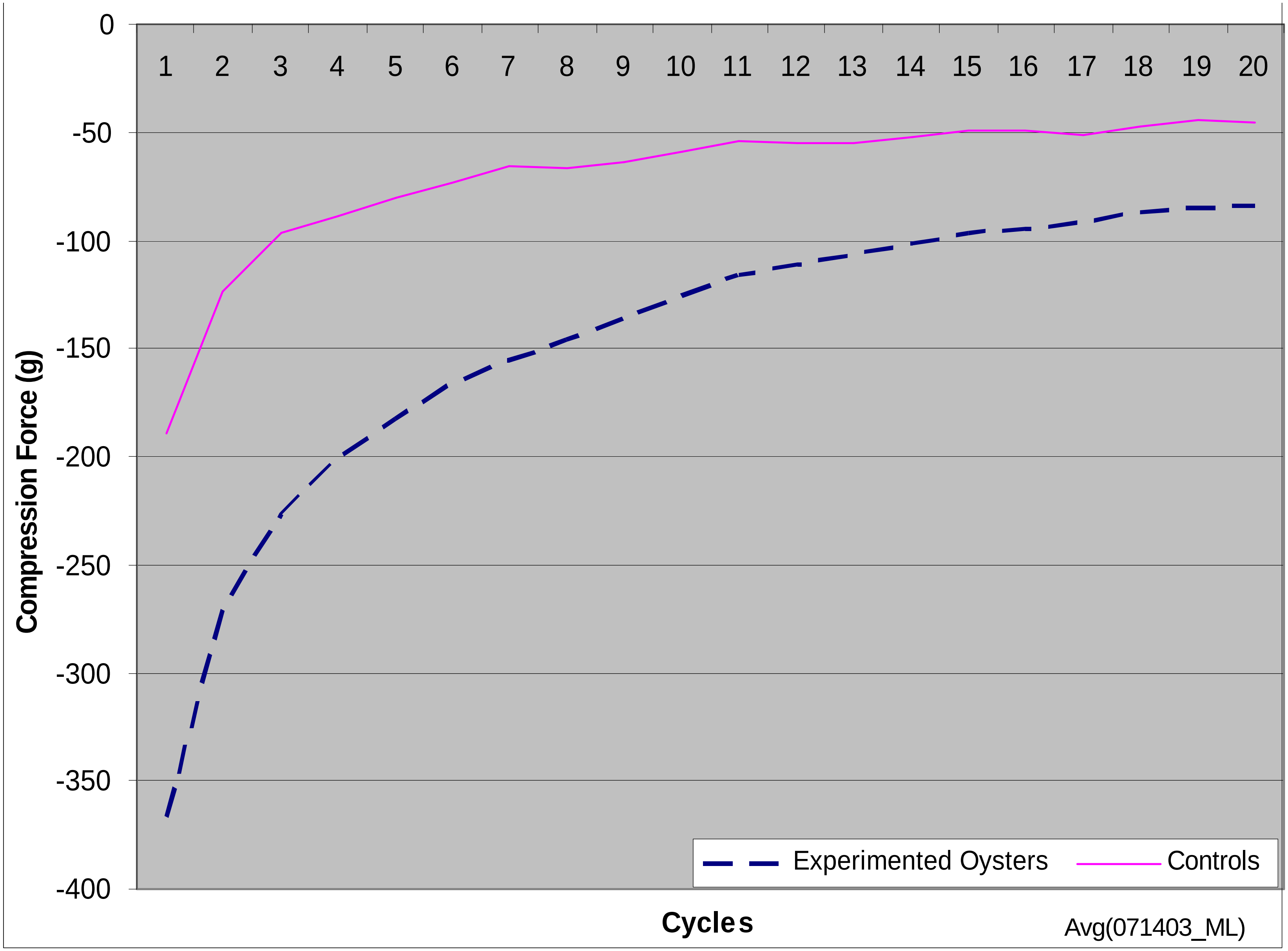
Experimented Oysters
Controls
Cycles
Avg(071403_AL)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-100
-150
-200
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-350
-400
Compression Force (g)
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11
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20
Experimented Oysters
Controls
Cycles
Avg(071403_ML)

Vita

Dan is an Extension Associate with the Department of Biological and Agricultural Engineering. He earned the degree of Bachelor of Science in Agricultural Engineering from Virginia Tech in 1988. He came to Louisiana State University in 1989 as a Research Associate in the Department of Biological and Agricultural Engineering with a concentration in post-harvest technology and finished the degree of Master of Science in Biological and Agricultural Engineering in 1994. His topic was "Extrusion Stabilization and Near Infrared Analysis of Rice Bran." He then accepted a position with the Louisiana Cooperative Extension Service as an Extension Associate in the Engineering Project with responsibilities for the Aerial Application Program, 4-H Science and Technology Program and the 4-H Automotive Program. He concurrently has been enrolled in the doctoral program at LSU and will graduate in December 2003.