1996 API Coke Drum Survey

Final Report

NOVEMBER 2003

American Petroleum Institute

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FOR
AMERICAN PETROLEUM INSTITUTE
Subcommittee on Inspection
Coke Drum Task Group

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American Petroleum Institute

Helping You Get The Job Done Right.℠

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Summary

In 1996 a survey was sent by the API Subcommittee on Inspection; Coke Drum Task Group, to companies operating coke drums in the United States and abroad. This was the third survey of similar nature conducted by the API. Fifty-four surveys were returned representing 17 different operating companies and a total of 145 drums. The purpose of this survey was to collect data covering a broad range of issues including:

1. General information
2. Design
3. Operating Information
4. Inspection Practices
5. Deterioration Experience
6. Repair Procedures

Three of the six areas, *Operation Information*, *Inspection Practices* and *Deterioration Experience* were not covered in the first two surveys. Additionally, this third survey asked more information in the other three areas as compared to the first two surveys.

Capstone Engineering Services, Inc. was contracted by the American Petroleum Institute (API) to collect, tabulate and develop correlation's with the data in an effort to increase safety and reliability of coke drum operation.

Findings (per Survey):

General:

1) 20% of the surveys (12% of the drums) (41% of Companies) reported that they had experienced a fire
2) Not all through wall cracks resulted in fires
3) There were **no** reported incidents of a drum crack causing a fire that damaged adjacent equipment
4) 94% indicated a desire to have an API Recommended Practice

Design:

5) New drum material selection has been towards increasing Chrome Moly alloy content
6) As observed in the 1968 Survey, no correlation between drum life and drum material was apparent
7) 40% indicated they had removable insulation around the skirt to aid in inspection of these locations

Operation:

8) No correlation between drum cracking and fill cycle time was found
9) Drum operating parameters such as initial quench rate and proofing quench practice rather than metallurgy appears to have a greater influence on drum cracking

Skirt Deterioration Experience:

10) Skirt cracking was reported by 78% of the surveys
11) 43% of these reported cracks propagated into the shell
12) 89% of the skirts with slots experienced cracking
13) Only 22% of the skirts without slots experienced cracking
14) In-line skirts accounted for 83% of the skirts that did not experience cracking

15) 75% of the skirts without cracking were skirts that had flush ground welds

16) 67% of the skirts without cracking were both in-line design and had flush ground welds

17) Skirts were replaced by 23%

18) Of the 23% that replaced skirts, recracking eventually occurred 43% of the time

Shell Deterioration Experience:

19) First bulge appeared sooner than first through wall cracks

20) Shell bulging was reported by 57%

21) Shell cracking was reported by 57%

22) Of the drums that bulged, 87% also experienced cracks

23) Cracking without bulging was reported only by 6%

24) Circumferential cracking was found 97% of the time

25) Most cracks and bulges were located in courses 3, 4, and 5 (course 1 is at the bottom)

26) Roll bond cladding was used the most and had a slightly better success rate, however the data set for explosion bond and plug weld cladding was small

Repair Procedures:

27) Shell repairs were performed from the OD by 26%

28) Of the 26% that performed OD repairs of ID cracking, 88% experienced recracking

29) Shell repairs were performed from the ID by 55%

30) Of the 55% that performed ID repairs, only 21% experienced recracking

Inspection Procedures:

31) The most common method of mapping bulges was manually as reported by 26 surveys. Responses from 14 surveys reported using laser mapping techniques

32) Considering drums four years and older:

- 100% of the surveys indicated that some form of inspection was performed during shutdowns
- 40% indicated that they performed some inspection during operation
- Frequency of internal inspection varied from one year intervals to 10 year intervals with an average of 4 years

Future Survey Recommendations:

34) Given the complexity of the design and operation of coke drums, it is anticipated that there would be minimal value in performing another industry wide coke drum survey in 10 years

35) If a survey was performed in the future, it is recommended to selectively survey younger drums made of similar materials and experienced fewer variations in cycle time and operation

Background

This survey was the third performed by the American Petroleum Institute. Previous surveys were conducted in 1968 and in 1980. The conclusions of these two reports as they appeared in the 1980 report are as follows:

1968 Survey:

a) Carbon steel drums bulged far more extensively than C-Mo drums before giving Through Wall Cracks.

b) Through Wall Cracks were circumferential. They occurred during quenching, steam cooling, or start up. Although cracks were extensive, no failures were catastrophic.

c) It appeared that thinner vessels had shorter life.

d) The report showed clearly that both C-Mo and Carbon Steel drums increasingly embrittled with time. Carbon Moly drums appeared to be more sensitive to embrittlement and cracking.

1980 Survey Summary:

A. Most of the reporting was on drums not included in the 1968 API report. Apparently many of these drums have been retired.

B. Review of service experience shows much less through [wall] cracking of drums than previously reported.

C. Ten companies reported on sixty coke drums.

D. Most of the more recent drums are primarily constructed of Chrome Moly rather than Carbon Steel and Carbon Moly.

E. No advantage of Chrome Moly over C-Mo is apparent except it appears that Chrome Moly in Graphite Coke service gives better service.

Review of both surveys showed that the 1968 survey did not conclude that Carbon Moly drums were more sensitive to cracking, rather, it was both the 1968 and 1980 authors opinion that increased embrittlement would likely result in increased cracking. The 1980 Survey conclusions state that there was no observed advantage in terms of service life for Chrome Moly over Carbon Moly drums.

1996 Survey Data

The line by line detailed data from the surveys is provided in Appendix 1. The results were reformatted with the question across the top. The next row refers to the question number from the original survey. The 54 survey responses are given in the following rows. At the bottom of the survey, three rows provide the number of “yes” responses to “yes/no” questions along with the percentage of “yes” responses compared to total number of responses for that question. **Since not all questions were answered by all surveys, results are given as a fraction and a percentage, based on specific answers over the total number of answers to that question.**

For data indicating a numerical value, minimum, maximum and average values are given in the last three rows of the tables.

The identification number given in the second column of the **General Information** section is for reference only. The first two digits of the identification number indicates physical surveys that were returned. Some surveys had multiple units or refineries on one survey, therefore the number after the dash indicates the column of data from the original survey. Therefore, when the first two numbers are the same for multiple surveys, the same company was responding. However, when multiple survey forms were submitted by one company, the groups of forms were split up to promote anonymity of the respondent.

In the 1996 survey it was found that a returned survey represented several different groups. When all the drums within a plant were the same design, age, and operation, they were all grouped together. As many as six drums were represented by one survey. When a plant had two or more sets of drums with each set having a different age or material of construction, one survey per set was used.

Much of the survey results are presented in terms of "percent of surveys". As a part of the follow-up, the number of drums per survey was gathered and used to evaluate answers in terms of "percent of drums". The results of the two methods were found to be very similar indicating minimal value in trying to recalculate any other results based on "percent of drums."

Care should be taken when using raw statistics presented in this report. Due to the wide range of drum ages, there could be considerable "age bias" in the results. Much of this age bias is due to the limited nature of any survey. Not every possible question was asked (even though the survey covered 18 pages and asked 250 questions).

1996 API Coke Drum Survey Report

1.0 General Information

The year of installation for coke drums varied from 1950 to 1997, the year that the survey was actually collected. Range of years in service accordingly was from 46 years to less than 1 year. When asked if any fires had occurred it was found that 11 of 54, or 20% of surveys had experienced fires in the past. In terms of numbers of drums, 12% of the drums had fires. Most of these fires were referred to as small or minor, none of the surveys indicated that adjacent equipment was damaged by a fire that resulted from a drum crack.

Ninety-four percent of the surveys returned indicated that they would benefit from an API Recommended Practice (RP) on coke drums.

2.0 Design

Table 2.01 shows a break down of the materials used in construction of the shell by survey. The most common was the Carbon ½ Moly material followed by the 1 Chrome material. Seventy-two percent used normalized shell materials while 70% post weld heat treated the original material. Specifically, 20% of the Carbon Steel drums were originally post weld heat treated, 71% of the C ½ Mo drums, and 85% of the Cr Mo steel drums were post weld heat treated.

Maximum shell thickness (located at the bottom, #1 course) varied from 0.56” to 1.64” in thickness.

Table 2.01
Frequency of Material Selection for Shell and Cone Materials

Shell and Cone Material	CS	C ½Mo	1 Cr	1-¼ Cr	2-¼ Cr
Number of Responses	10/54	17/54	16/54	9/54	2/54
Percentage	18.5%	31.5%	29.6%	16.7%	3.7%

Cladding thickness varied from no cladding (one unit that has been since taken out of service, no additional data available) to a minimum thickness of 0.078” up to a maximum thickness of 0.127”. The cladding/liner material was predominately type 410S stainless steel as shown in Table 2.02. Type 410S stainless steel is a low carbon version of 410 stainless steel. Combining the two versions gave a 75.5% usage. The least common material used was type 405 stainless steel. Table 2.02 also gives the reported methods of attaching the liner to the shell. Roll bonding was the most common used method with some use of explosion bond cladding and plug welded cladding. One survey reported the use of strip lining.

Table 2.02
Frequency of Material Selection for Cladding Materials

Cladding Material	Surveys	Percentage
405	13/53	24.5%
410	14/53	26.4%
410S	26/53	49.1%
Roll Bond	38/52	73.1%
Explosion Bond	9/52	17.3%
Plug Welded	5/52	9.6%

Four surveys indicated use of an austenitic stainless steel for weld overlay (i.e. weld overlay on the ID of nozzles) or for joining the cladding over the seam welds and girth welds as seen in Table 2.03. Nickel based welding electrodes were predominately used.

Table 2.03
Frequency of Material Selection for Welding Clad Materials

	Weld Overlay		**Liner Joint**	
ENiCr Fe-3 ('INCO 182 type')	19/43	44.2%	18/49	36.7%
ENiCr Fe-2 ('INCO A type')	11/43	25.6%	13/49	26.5%
308/309	4/43	9.3%	4/49	8.2%

Skirt material selection (the top ring of skirt material attached directly to the drum) followed very closely with the drum material selection. However, many of the C ½ Mo drums used carbon steel skirts.

Seventy-six percent of the skirts were slotted. Ninety-five percent of those with slots also had put keyholes at the end of the slots. Inline design versus a lap joint design was split 50/50.

Deheading devices (handling devices to remove the lower head quickly, not necessarily bolt replacement devices) were used on 64% of the equipment. There were 12 users that had the deheading device attached directly to the drum while 13 indicated that the deheading device was attached to the surrounding structure.

3.0 Coke Drum Operation

Coke drums operate as a batch process alternating between two drums as shown in Figure 3.01. Feed is constantly run through a coker heater which heats the oil to approximately 900 to 950 ^{o}F. The hot oil is then directed into the empty coke drum (Drum A in Figure 3.01) to start the fill cycle.

The hot oil feed to the coker unit often contains sulfur. The weight percent of sulfur ranged from 0.6% to 5.5%.

The surveys indicated that 72% of the drums produced Sponge coke, 19% produced Shot coke while 9% produced a mixture of Shot and Sponge coke. No responses indicated production of Needle / Graphite coke.

A drum cycle can be broken down into a sequence of steps. Much of what is happening in a drum is reflected by the inlet temperature as shown in Figure 3.02.

During the fill portion, the inlet temperature is a function of the furnace outlet temperature and therefore is fairly constant. After the fill is completed, steam stripping is done to remove light ends from the coke. This is done at a lower temperature than the coke feed.

As a transition from steam stripping to water quench, some users employ a **proof quench procedure** that injects an initial high rate of quench water in an effort to keep open the channel through the center of the coke drum. This causes a rapid decrease in the inlet temperature.

A graphical representation of a proof flow in the quench water flow rate in gallons per minute (gpm) is shown in Figure 3.02. The proof flow duration is comparatively short, on the order of less than one minute to 10 minutes and is immediately followed by the initial quench water flow rate. Reported proofing rates varied from 300 gpm up to 1,100 gpm.

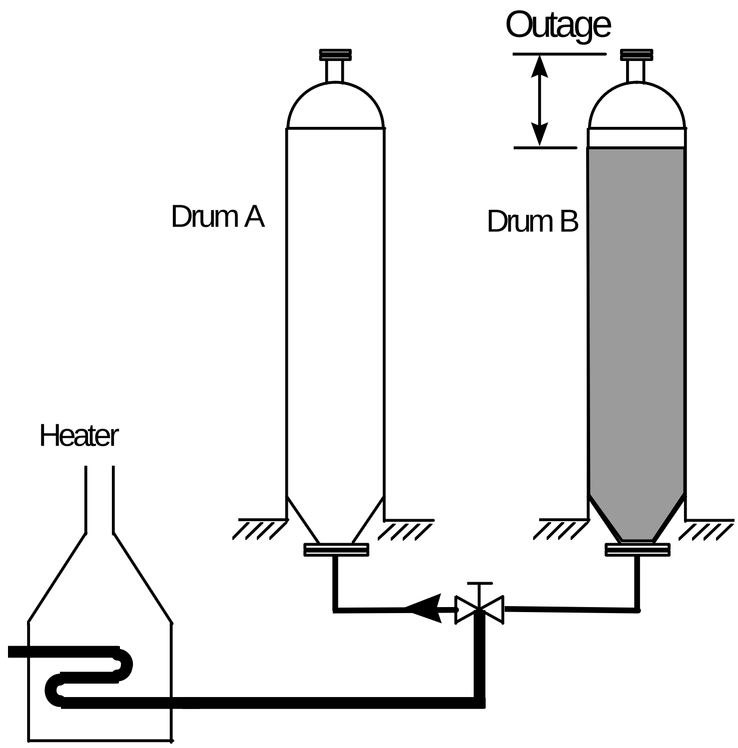


Figure 3.01

The quench water flow rate varied from 8 gpm to 1,000 gpm with an average just over 200 gpm. Typically this initial quench rate is stepped or ramped upward to higher flow rates. Maximum final quench rate was reportedly 3,100 gpm with an average of 838 gpm. To determine the effect that the minimum and maximum quench rates had on the average, the highest quench rate (3,200 gpm) and the two lowest (8 and 10 gpm) were removed from the data set. The average quench rate became 822 gpm.

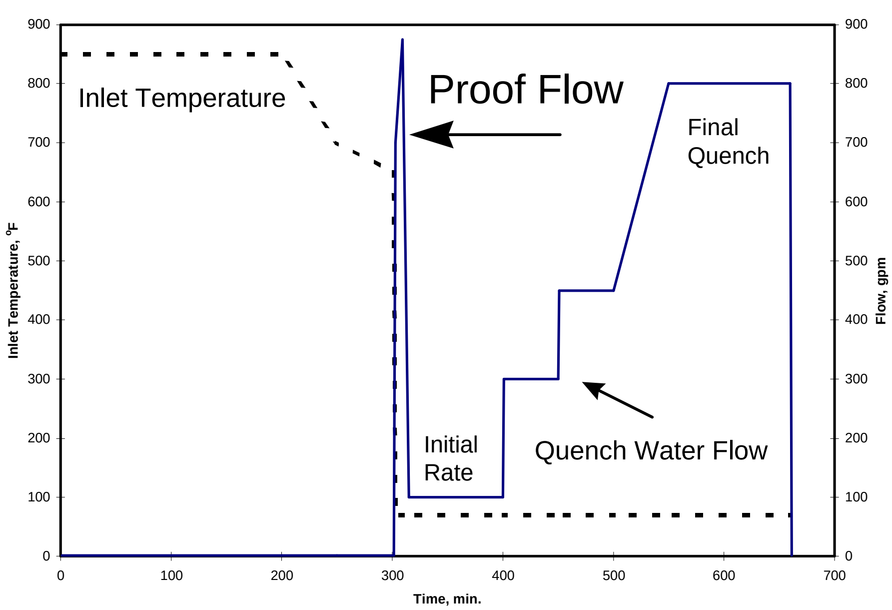


Figure 3.02

After the quench water fills the drum, 72% of the surveys indicated that a soak time was used. For those who used a soak period, the duration varied from 20 minutes to 6 hours.

After soaking, the drum is drained of water, the bottom and top heads are removed and a pilot hole is drilled through the coke from the top to the bottom of the drum. The next step is cutting which uses rotating high pressure water streams.

After all of the coke has been removed from the drum, the top and bottom heads are reattached. Reheading is accomplished by automatic methods such as hydraulic rams or by manual methods such as winching techniques. After reheading, the drum is pressure tested using steam to determine if there are any gasket leaks. The steam also removes air from the drum.

The steam is also used to initiate a drum preheat. This is done by flowing steam from the bottom of the drum to the top. Vapor preheat is performed by diverting overhead vapors of the adjacent drum being filled. The hydrocarbon vapor is flowed from the top of the empty drum down and out the bottom to the fractionation vessels. Vapor preheating the drum lessens the thermal shock experienced when hot liquid is introduced into the drum.

When the fill cycle of the drum reaches its outage level, which is generally measured from the top flange (as depicted in Figure 3.01), the flow from the heater is diverted from the first drum to the second drum. The survey responses for outage levels ranged from a distance of 10 feet to 26 feet with an average distance of 18 feet. After the flow is diverted from the first drum, steam is introduced while the fill cycle now begins on the second drum. The cycle is now repeated. Some use a series of three drums and therefore the fill cycle represents one third of the total cycle.

Fill cycle duration, shown in Figure 3.03, ranged from 10 hours to 24 hours. The vertical axis is the number of survey responses. Each vertical bar represents the range from the preceding bar up to the indicated hours, i.e., the bar at “12” includes drums with 11 and 12 hour fill cycles. Average fill time was found to be 15 to 16 hours.

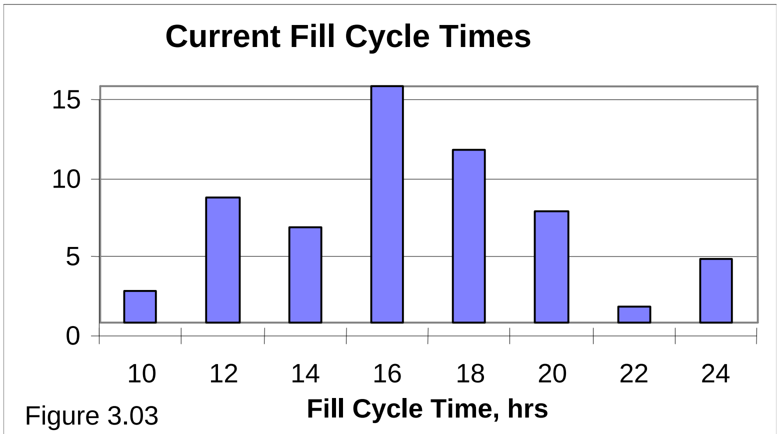


Figure 3.03

Question 3.16e of the survey asked what was the original fill cycle time. The answers ranged from 10 hours to 24 hours with an average of 20 hours.

Since the fill times have changed over the life of some of the older drums, information was gathered on the original fill cycle duration as well as the number of years that that fill cycle was employed. Up to five different fill cycles were reported on a single unit.

4.0 Inspection Practices

The purpose of this section was to establish what users are doing in terms of inspection frequency as well as methods. For drums older than four years:

> One hundred percent of the surveys indicated that some form of inspection was performed during shutdowns. Additionally, 40% indicated that they performed some inspection during operation. Frequency of internal inspection varied from one year intervals to 10 year intervals with an average of 4 years. One hundred percent of surveys indicated that scaffolding was used to inspect the ID of the drums.

A variety of inspection methods were used, visual inspection was the most common for both ID and OD inspection. Both wet and dry magnetic particle techniques, shear wave ultrasonic techniques, and acoustic emissions testing (AET) were also listed as methods used. Twenty-seven percent of surveys indicated that they had removable insulation around shell welds, while 40% indicated they had removable insulation around the skirt to aid in inspection of these locations.

The most common method of mapping bulges was manually with 26 surveys while 14 surveys used laser mapping techniques.

Methods used for ID surface preparation included high pressure water blasting, sand blasting, and power wire brush buffing. External preparation used similar techniques however it was more common to use power wire brushing.

The most common method for on-stream detection of OD cracks was visual examination. Shear wave ultrasonic testing was used by five surveys, wet fluorescent magnetic particle testing used by four and AE testing used by two. For monitoring known indications, shear wave inspection was reported most often (25 times), AE testing was reported on seven surveys, visual testing five surveys, and wet fluorescent magnetic particle testing reported once. Nine surveys indicated success with ‘continuous’ monitoring out of a total of 13 responses. Visual and dry magnetic particle testing were the most common methods of ‘continuous’ monitoring indicating that the referred to monitoring could be classified as ‘very frequent’, not actually continuous.

The frequency of foundation inspection varied from 6 months to 5 years.

5.0 Deterioration Experience

The survey asked users about coke drum experience for different damage mechanisms. These included skirt bulging and cracking, shell bulging and cracking, clad cracking, corrosion and disbonding.

Also, the survey asked questions on insulation support ring welds. For those that did have insulation support rings, 6/21 (29%) of the surveys had experienced through wall cracking at these welds, while 11/21 (52%) had experienced cracking that did not extend all the way through the wall. For this reason, many users have utilized welded studs or a combination of welded clips with slots that bolt to the insulation support rings.

Several cases of cracking have been reported related to external attachment welds. Early designs incorporated attachment of the drilling deck and derrick to the top of the two drum pair. Cracks have been found in both the attachment gussets as well as in the drum. Similar experiences were noted for piping support structures that were welded to the drum.

There was at least one case of external corrosion under insulation (CUI) leading to cracking. An insulation support ring near the top of a drum was welded to the shell. This formed a dam that held water in the insulation as well as holding the water in contact with the shell. The combination of reduced wall thickness from CUI and the local stiffness of the support ring reportedly induced a crack that propagated from the OD.

5.1 SKIRT DETERIORATION

Seventy-eight percent of the surveys had experienced skirt cracking while only 13% had experienced skirt bulging. Eighty three percent of the skirts had slots. Of those that had slots, 89% had experienced cracking. Only 22% of the skirts without slots experienced cracking. It was found that in-line skirts accounted for 83% of the skirts that did not experience cracking. Similarly, 75% of the skirts without cracking were skirts that had flush ground welds. Combining the two, 67% of the skirts without cracking were both in-line design and had flush ground welds. As stated earlier, these results might be skewed due to an age bias (newer drums have less cracking).

There are two different primary areas of skirt cracking:

1. On either side of the skirt to shell weld, and
2. Associated with slots and keyholes.

5.1.1 Skirt to Shell Weld Cracking

Table 5.1 gives a break down of the various types of skirt cracking while Figure 5.1 displays a sketch of the crack locations. Evaluating the combined cracking at skirt to shell welds (A,B,&C),56% had experienced some cracking either above or below this weld. The more serious cracking, i.e. cracks that had propagated into the shell, accounted for 43% of reported cracks. There were reports of two types of shell cracking; cracks that start from the OD (labeled A_{OD}), and cracks that start from the ID of the skirt (labeled A_{ID}). The survey did not distinguish between these two locations, however, informal polling of user representatives indicated that the OD cracking was more common but ID cracks have been found. Slightly less cracking was confined to the skirt, with 39% of surveys experiencing cracks at this location.

Cracking was found to propagate on the skirt from both the outside and inside of the skirt (location B and C). The most common cracking took place from the outside with 63%, while 26% of cracking occurred from the inside only. Eleven percent of the surveys had cracking both on the inside and outside. The length of service time until cracks were noticed varied from 1 year to 10 years. Skirt cracks varied in length from 1/8" to the complete circumference of the vessel.

5.1.2 Slot and Keyhole Cracking

The most common location of cracking was at the keyholes and slots (location D). Over 71% of the users experienced cracking at the keyhole while 36% saw cracking at slots. A combination of the two, cracking at keyholes and slots, was slightly more with 76%. Generally the cracks at the slots were much shorter than those at the skirt weld.

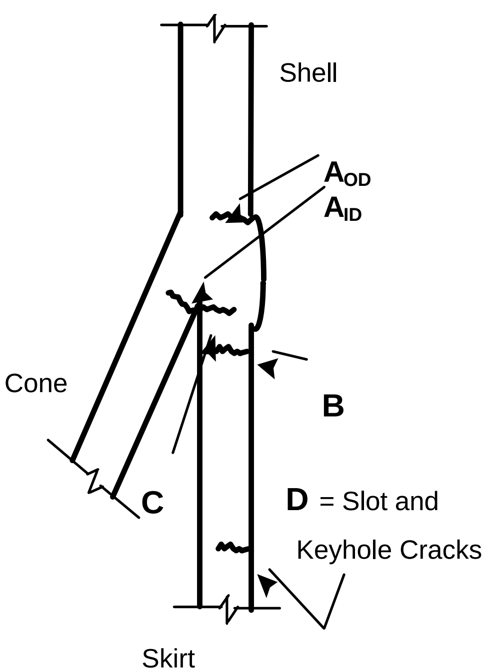


Figure 5.1

Table 5.1.1
Skirt Cracking Results

Description	Location	Percent Cracking
Cracking at Weld	A,B&C	56%
Cracking into Shell	A	43%
Cracking from Skirt OD	B	63%
Cracking From Skirt ID	C	26%
Cracking at Slots / Keyholes	D	76%
Total Cracking in Skirts	A,B,C,&D	78%

5.2 SHELL BULGING

Fifty seven percent of the surveys indicated that service induced (i.e. not fire damage) bulging had occurred in their drum. The average time until the first **observed** bulge was 11 years (there were varied levels of accuracy in detecting when bulging occurred). This coincided with the reported experience of the newer drums. Based on the 1996 data, the last year of installation with no bulges was 1984 (12 years). Using a cut-off of five years, i.e. drums installed before 1991, 72% reported bulging. When considering drums installed before 1984, 80% of the surveys reported bulging.

The number of bulges ranged from 1 to 12 bulges per drum. All surveys reporting bulges indicated that they grew outward as well as an additional 27% indicating that they also grew inward. Maximum and average lengths are given below in Table 5.2.

Table 5.2

Maximum and Average Bulge Results

Question	Maximum Answer Range	Average Answer
Maximum Vertical Length	3” to 620”	65”
Average Vertical Length	2” to 50”	23”
Maximum Circumferential Length	5.5” to 1,074”	547”
Average Circumferential Length	4” to 1,074”	408”
Maximum Radial Bulge	.31” to 6”	3”
Average Radial Bulge	¼” to 6”	2.1”

Clearly the bulges were much longer in the circumferential direction than in the vertical direction.

Thirty-six percent indicated that disbonding of the cladding had occurred. Disbonded cladding only occurred on drums that had bulged (location of disbonding was not recorded).

5.3 SHELL CRACKING

Fifty-seven percent of the surveys reported cracking in the shells. The number of cracks in each shell ranged from one crack to “too many to count”. One survey reported 300+ cracks. Those listing “many” and the 300+ reported cracks on survey 41 were reduced to 100 cracks to aid in graphing the data.

Considering just the surveys reporting cracks in the shell, 50 was the maximum reported number of cracks that propagated through the wall, with an average of six cracks in each shell.

Seventy-one percent indicated that cracks occurred at bulged areas. Cracking **did not only** occur at bulges however, 83% reported having cracks in non-bulged areas. Review of the answers given to this question revealed a mixture of interpretations. There were several cases where the respondent considered cracks at the edges of bulges to be in non-bulged areas. Therefore, the 83% reporting cracks in non-bulged areas is probably high.

There was a definite trend of cracks in bulged drums. Specifically, 87% of drums with bulges contained cracks. Table 5.3 gives the data of the 13% exceptions that did not follow this trend. This table shows that four surveys indicated that drums have bulged and not cracked, while four other surveys reported cracking but no bulging.

Table 5.3
Drums with Either Cracking or Bulging Only

Survey Number	4	5	16	18	14	24	25	39
Has the shell bulged	**Yes**	**Yes**	**Yes**	**Yes**	No	No	No	No
Has the shell cracked	No	No	No	No	**Yes**	**Yes**	**Yes**	**Yes**
Total number of cycles at survey	9386	9386	5246	5994	5970	1971	6132	2738
Drum Material	C-$^{1}/_{2}$Mo	C-$^{1}/_{2}$Mo	C-$^{1}/_{2}$Mo	1 ¼ Cr	C-$^{1}/_{2}$Mo	2 ¼ Cr	C-$^{1}/_{2}$Mo	1 Cr
Clad Material	405	405	410S	410S	410S	405	405	410

ID versus OD initiated cracking was almost split. Sixty-four percent of surveys indicated that cracks initiated from the ID while 71% indicated that cracks initiated from the OD.

Ninety-seven percent indicated that cracks were primarily circumferential. Only one survey indicated that only longitudinal cracks were present in the shell. However, 52% indicated that they had experienced both longitudinal & circumferential cracking. Sixty-eight percent indicated that craze cracking of the shell had occurred. As stated earlier, 29% indicated that through wall cracks had occurred at insulation support rings. For non-through wall cracking, 52% experienced problems at insulation support ring fillet welds.

After crack repairs had been performed, 55% of surveys reported that cracking had re-occurred.

5.4 CLADDING & CRACKING

Thirty percent of the surveys indicated that craze cracking had occurred in the cladding. No one indicated that corrosion had initiated any cracking but that pitting and general corrosion had occurred A total of 19% indicated some type of corrosion damage, such as pitting, general corrosion or other types of corrosion.

6.0 Repair Procedures

6.1 SKIRT ATTACHMENT:

Twenty-three percent of surveys indicated that the skirt had been replaced (either partial or full). Of those who had replaced the skirts, 45% indicated that replacement skirt had also cracked eventually. Only 3 of the 11 survey changed the skirt material while the other 8 used the same material of the previous skirt. Only one survey indicated that slots were added, while three indicated that slots were removed.

The survey asked if skirt OD cracks were repaired by grinding and rewelding the crack instead of replacing the skirt. To this question, 54% of the surveys responded that they had performed this type of repair. One half of these surveys experienced cracks reoccurring. This indicated only a slightly lower success rate than skirt replacement. The survey did not request information on intervals of recracking. Generally, it has been industry practice to remove and repair cracks until recracking keeps occurring within shorter time intervals. At some point skirt replacement is often performed.

Most surveys used a preheat for either the skirt attachment welds (86%) or welds other than the attachment (54%). Use of a local torch, a band of electric heaters, or global burner were used for preheating for skirt repairs. Post weld heat treatment was used 57% of the time.

6.2 SHELL REPAIRS

Of those who had ID cracks, 26% attempted to repair those cracks from the OD. Eighty eight percent of those experienced subsequent cracking. Fifty-three percent repaired ID cracks from the ID and 21% of those subsequently cracked. OD cracking was repaired from the OD 47% of the time and 60% of those welds ended up cracking.

From these sets of numbers it appears that the lowest repair success rate is for ID cracks repaired from the OD. The highest success repair rate is for ID cracks repaired from the ID. Only one survey reported the use of a temporary external patch to cover over a crack. It was reported that they did not experience any cracking of the patch.

While the success rate may be lower for OD repairs, there is a significant advantage in that repairs can be performed with minimal down time. Once the OD repair is made, ID repairs can be scheduled in advance.

Repairs by flush patch windows were used 11% of the time for cracks and 13% for bulges. Replacement of courses were performed 9% of the time for cracking and 15% for bulging. Typically, only a single course was replaced at a time, however it was reported that up to 3 courses were replaced at one time.

Of the four surveys that reported use of a de-embrittlement heat treatment to reduce cracking, only one indicated success (1 ¼ Cr Drum) with the procedure while the 3 others, (1 Cr Drums) indicated that the procedure was unsuccessful.

6.3 CLADDING REPAIRS

Only one case of strip lining was used over a failed cladding area. Twenty percent attempted to remove and repair craze cracking in the cladding. The weld materials were rated as either “good” or “poor”. While there was no definition to these terms, cracking was the most often cited reason for bad performance of these materials.

The nickel based weld materials were rated good or very good in almost all cases where used; 100% for ENiCrFe-2 (INCO A type) and 92% for ENiCrFe-3 (INCO 182 type). The 309 type of stainless steel material was rate good to extremely poor (one survey reported “major cracking during first run and all was removed”) No use of 308 stainless steel was recorded. One use of “Cryotherm 60 (Champion)” was reported to have performed very good.

If sulfidation resistance was the primary concern, it is anticipated that type 309 stainless steel would have performed better than the nickel based materials. Rather, it appears that matching the thermal expansion rate is key which means that the nickel based materials would perform better than an austenitic stainless steel.

7.0 Trends and Correlations

7.1 MATERIAL DESIGN TRENDS

A study of the trends over time for different materials of construction and different design parameters was investigated. The coke drum materials were grouped in three groups for histograph charts showing materials of construction before the first survey (1968), second survey (1980) and then up to present. The number of surveys is shown for the various materials.

The Chrome Moly materials were graphed two ways. For reference, the Chrome Moly materials were split into three types; 1 Chrome, 1 ¼ Chrome, and 2 ¼ Chrome. Since the size of each of these groups was small, these Chrome Moly materials were combined when correlating performance.

The first component examined was the skirts. Figure 7.01 shows skirt materials constructed in the years 1950 to 1997. Initially, carbon steel was the primary material used for skirt construction. From

1980 to present 1-Chrome and 1¼-Chrome materials were primarily used. Figure 7.02 shows a linear grouping time line across the bottom with the different shell materials represented on the y-axis.

Similar plots for shell and cone materials are shown in Figure 7.03. Again, Carbon Steel and Carbon ½-Moly were the predominate material in early coke drums. This trend has shifted towards 1-Chrome and 1¼-Chrome materials including 2¼-Chrome materials in 1980 to 1997. This is shown again in a linear plot in Figure 7.04.

Cladding material selection began an increase in the use of 410S stainless steel (a low carbon version of type 410) over time as shown in Figures 7.05 and 7.06. Figure 7.07 shows the weld materials that have been used to join the cladding liner on the inside of the vessel. Only three cases of a stainless steel material have been reported, these were pre 1960's. Since then only nickel based filler metals were reported.

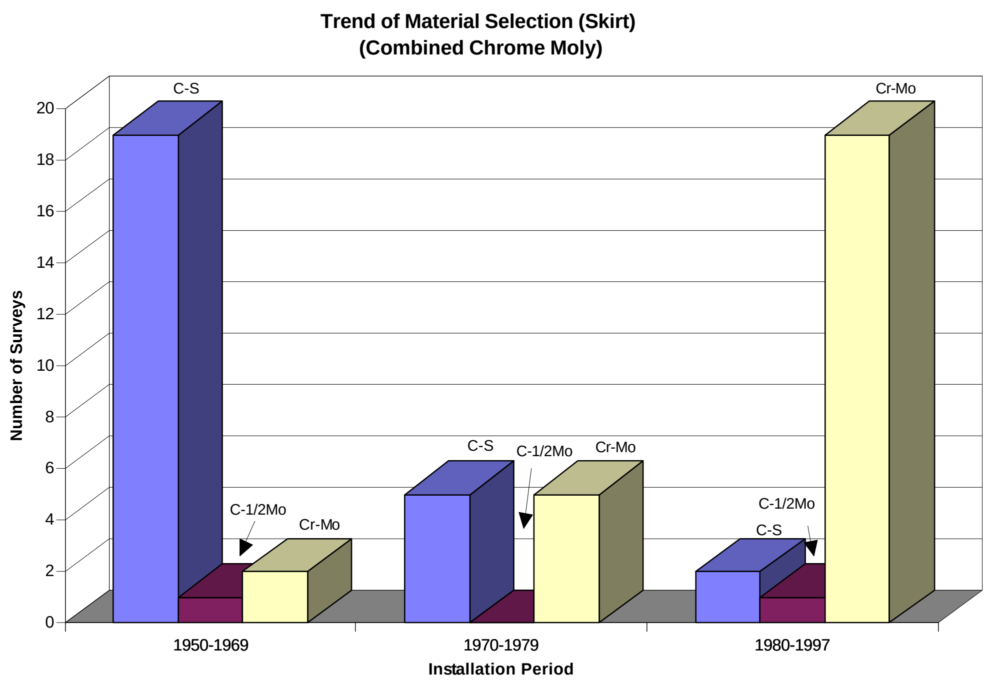


Figure 7.01

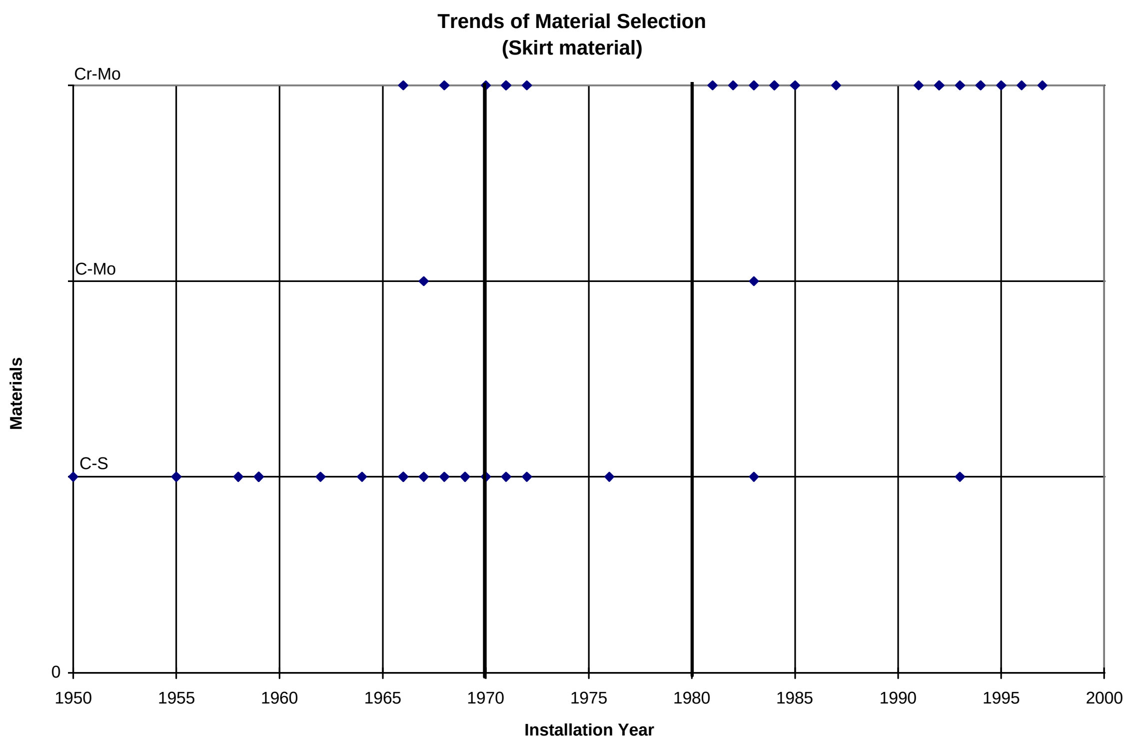


Figure 7.02

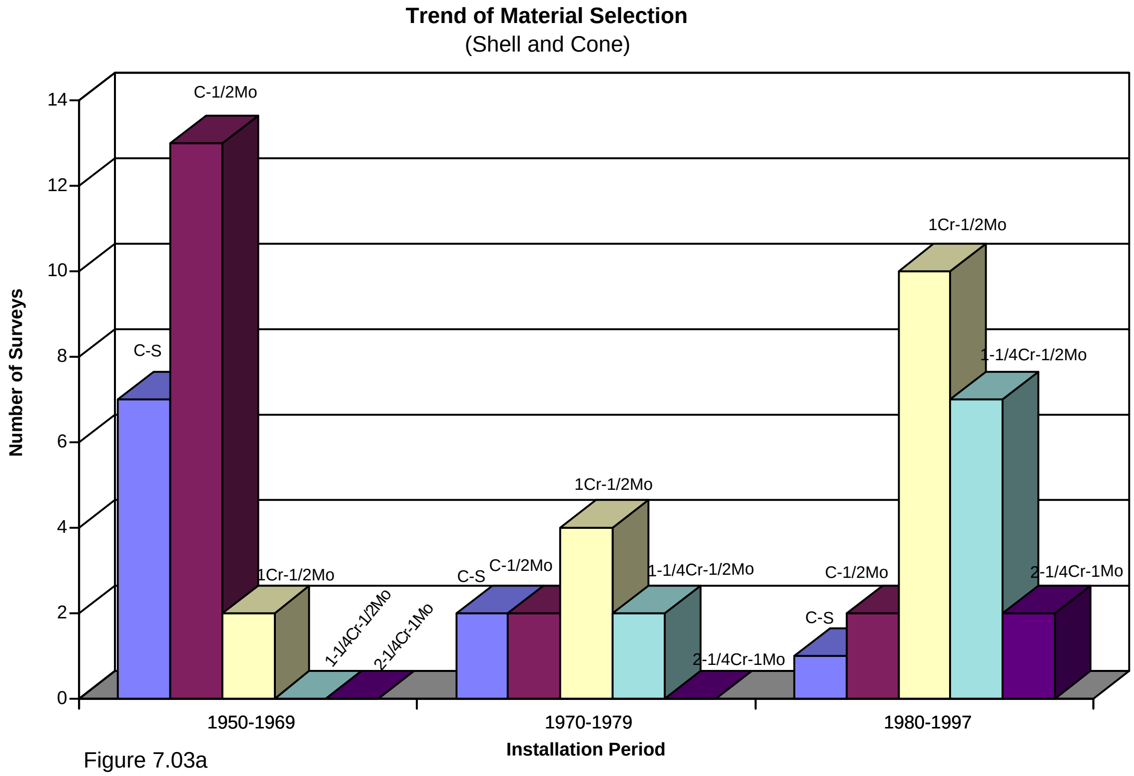


Figure 7.03a

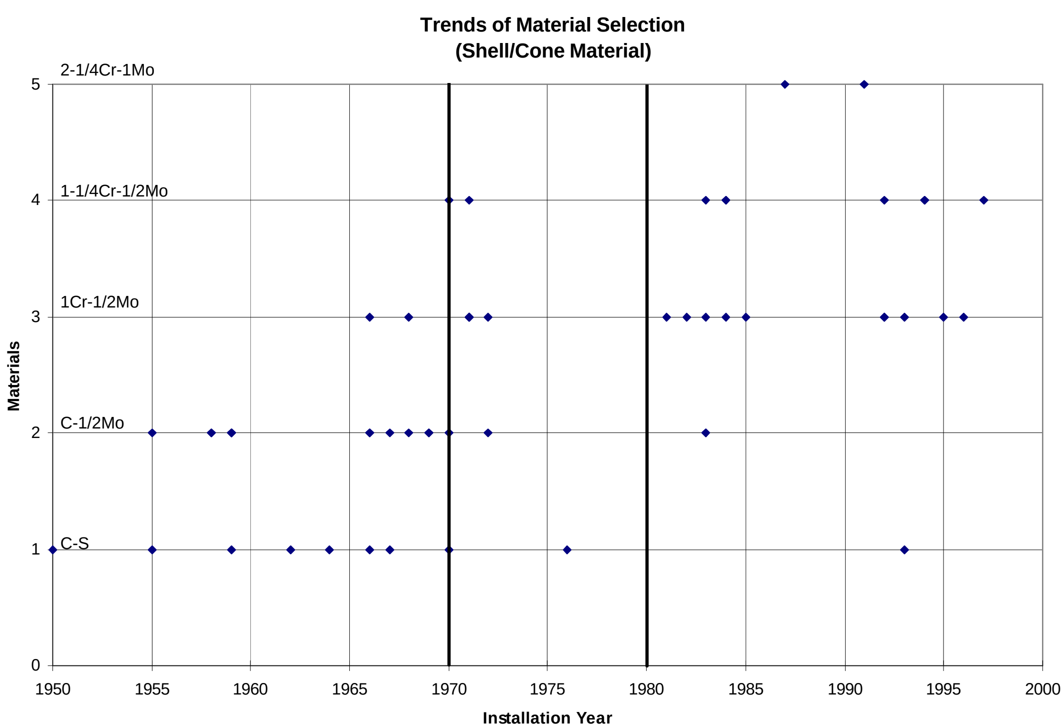
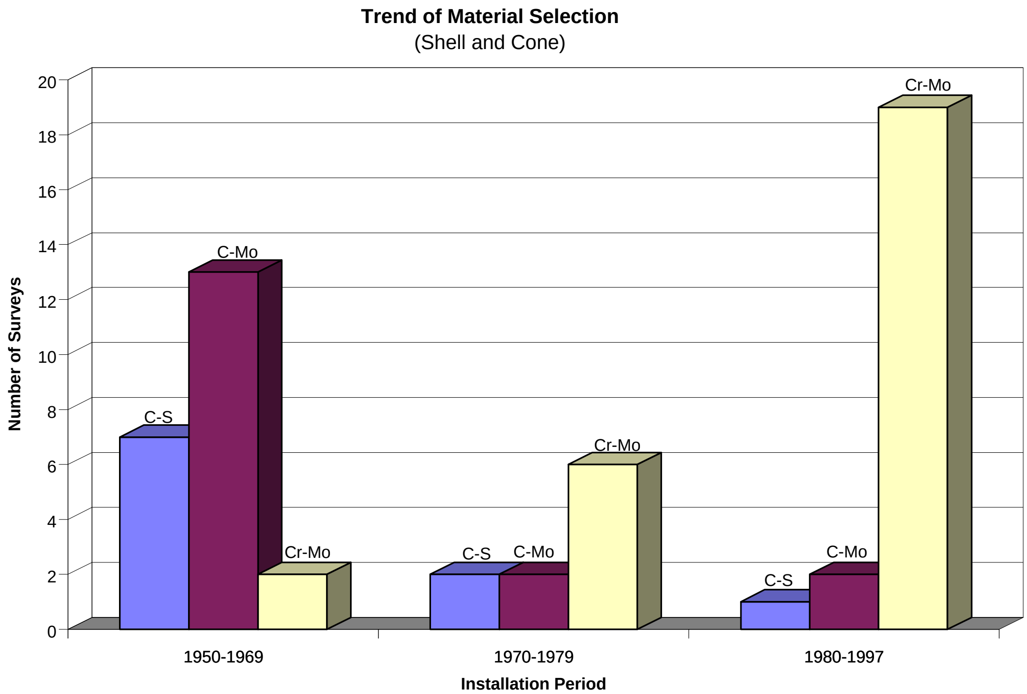


Figure 7.03b



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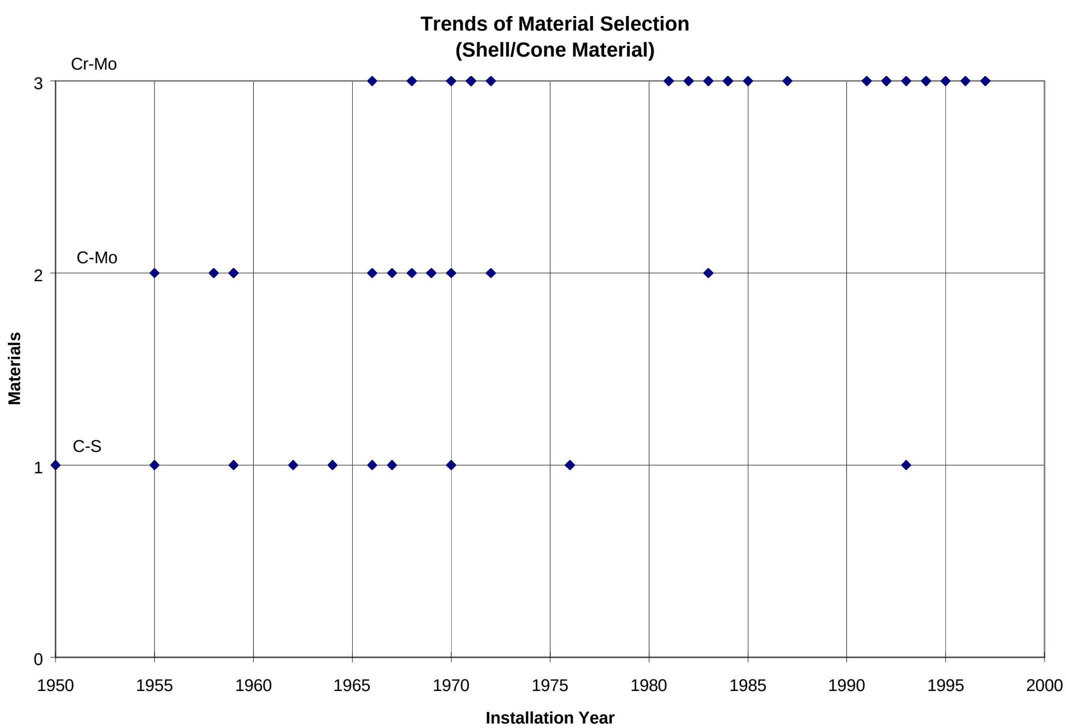

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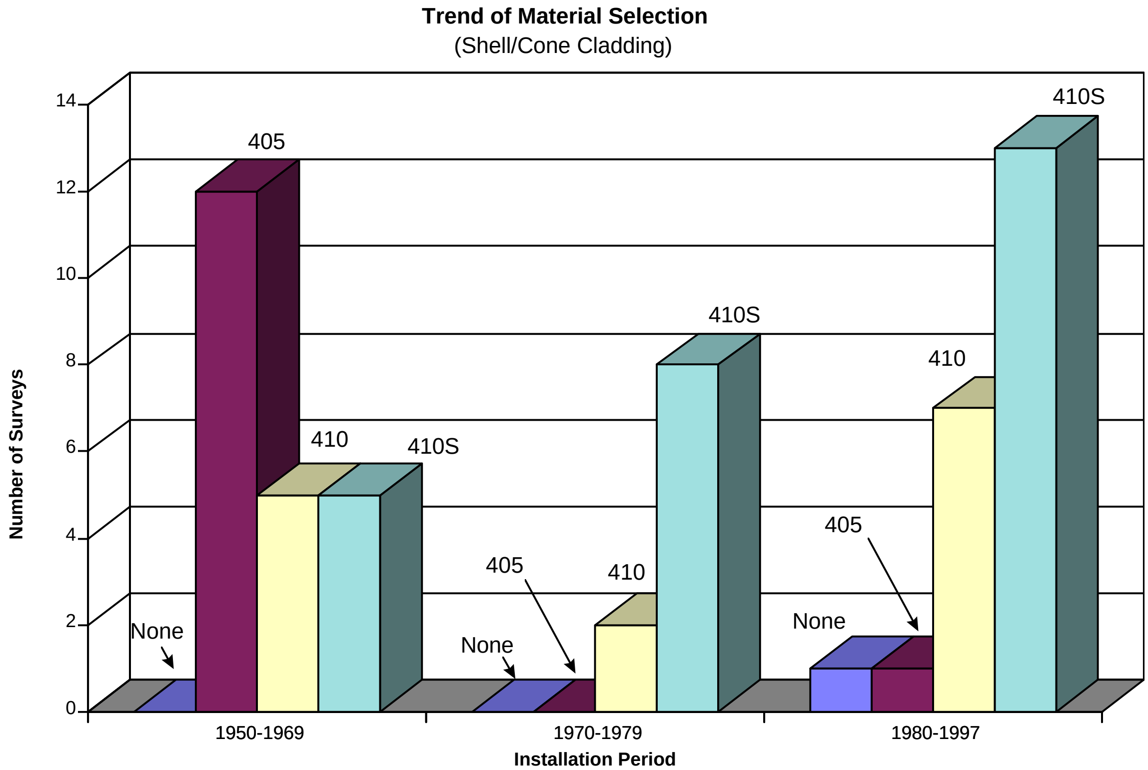


Figure 7.05

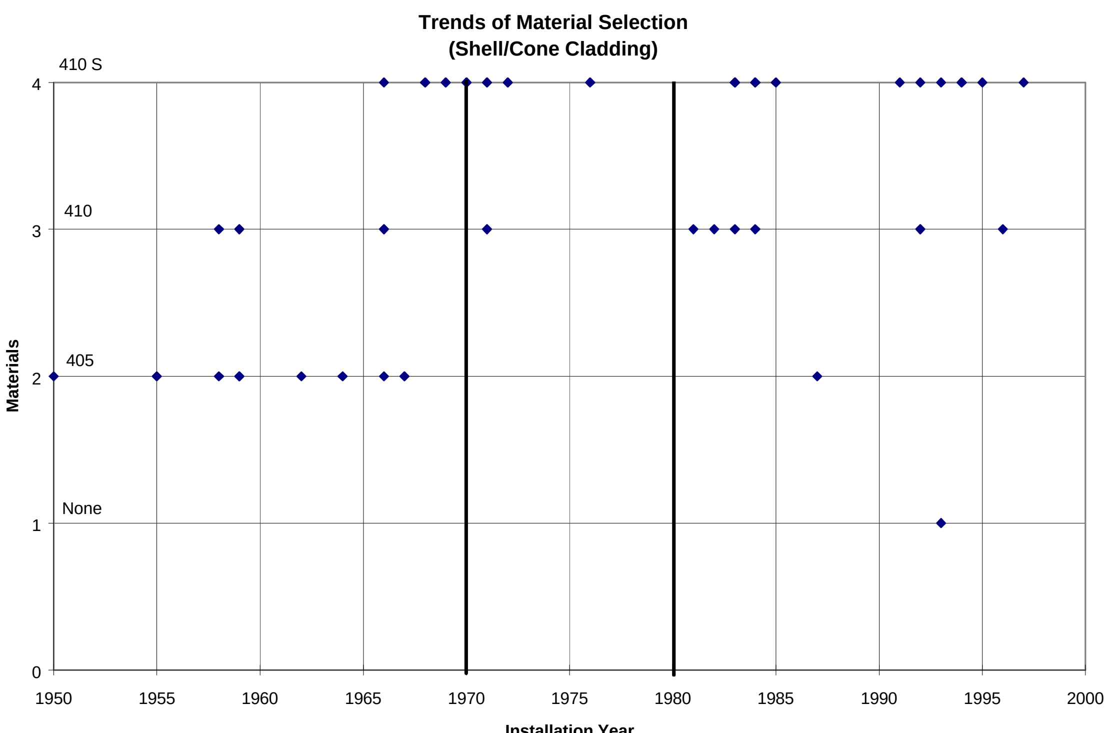


Figure 7.06

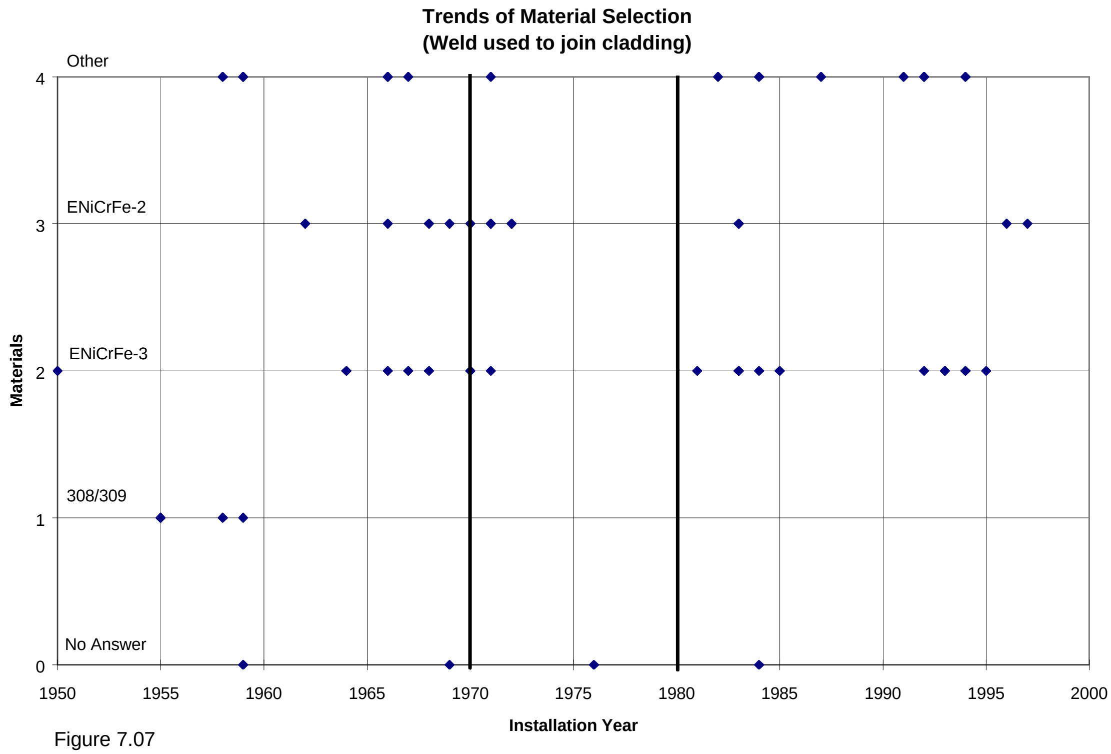


Figure 7.07

7.2 DIMENSION TRENDS

The trend in skirt wall thickness was also investigated and these results are shown in Figure 7.08. Shell wall thickness versus year of installation is shown in Figure 7.09. Drum capacity showed an increase in newer drums. This is seen in both increased height for newer drums as well as an increase in drum diameter. The ratio of drum diameter over thickness was calculated.

Drum diameter is shown in Figure 7.10. Drum diameter shows increasing drum diameter with newer drums. Diameter divided by maximum wall thickness was also plotted in Figure 7.11. This value gives a relative stiffness for diameters. A small diameter drum with a thick wall produces a small value as opposed to a larger diameter with a thinner wall produces a larger value.

Drum height versus installation year also shows a slight increase in drum height in newer vessels as seen in Figure 7.12. Figure 7.13 shows drum capacity in tons. Surveys that did not respond to this question were assigned a calculated value using 70 pounds per cubic foot and an outage of 15 feet below the head to shell weld. This plot showed an increase in capacity for newer drums.

This graph marks the first usage of a trend line. Trend lines were included in the graphs when possible. Straight lines were plotted as a linear array while the curved lines were plotted as a second order polynomial function (parabolic). The “R^2” value is also plotted to show how well the curve fit the data. Only the black diamond data points were used to plot trends. The open square data points are for reference information. Separate trend lines for each group of drum materials was also included for several design parameters. The type of line used was based on which function (linear or polynomial) gave the best R^2 value. The larger the R^2 value, the better the fit, the best fit approaches a value of 1.

Skirt Wall Thickness vs. Installation Year

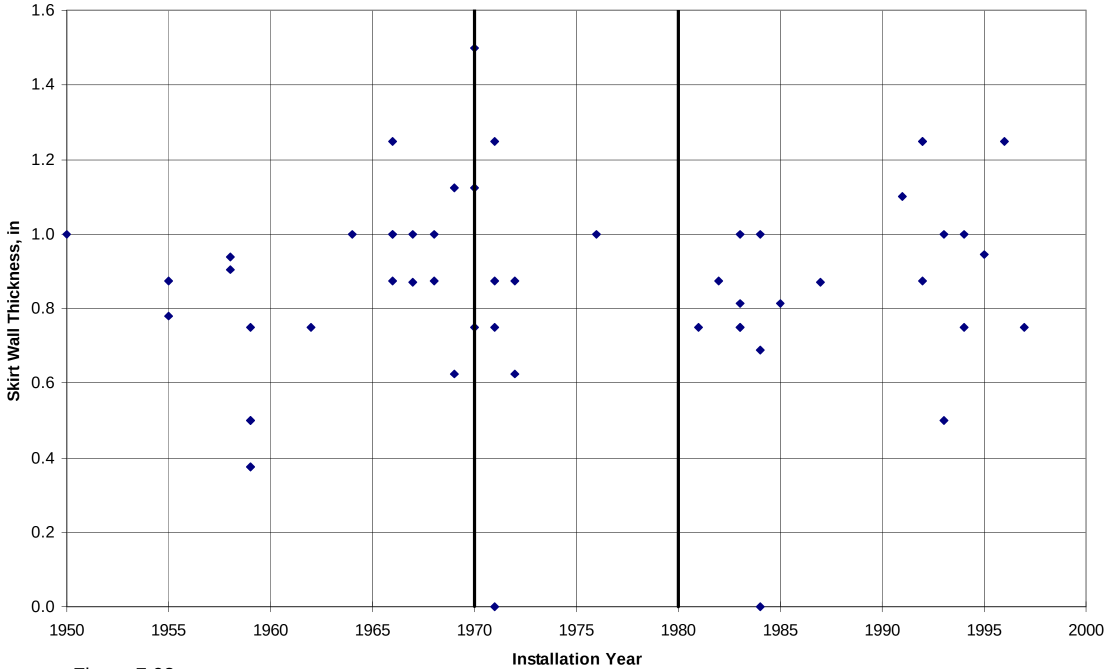


Figure 7.08

Shell Thickness (Bottom Course) vs. Installation Year

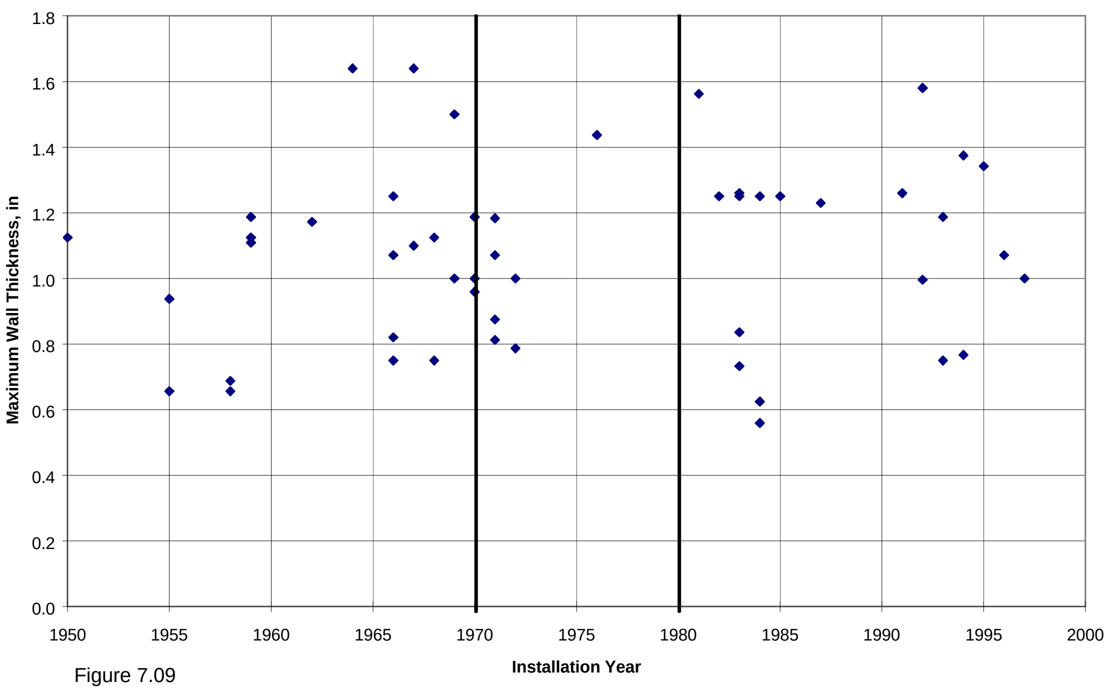


Figure 7.09

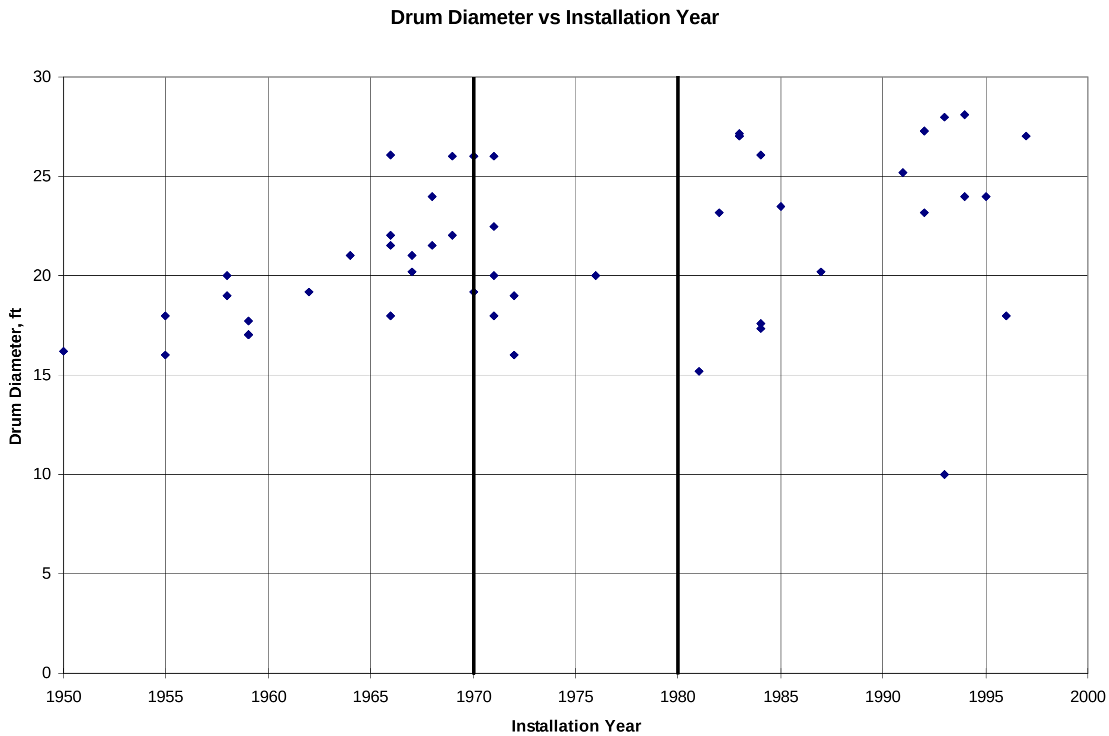


Figure 7.10

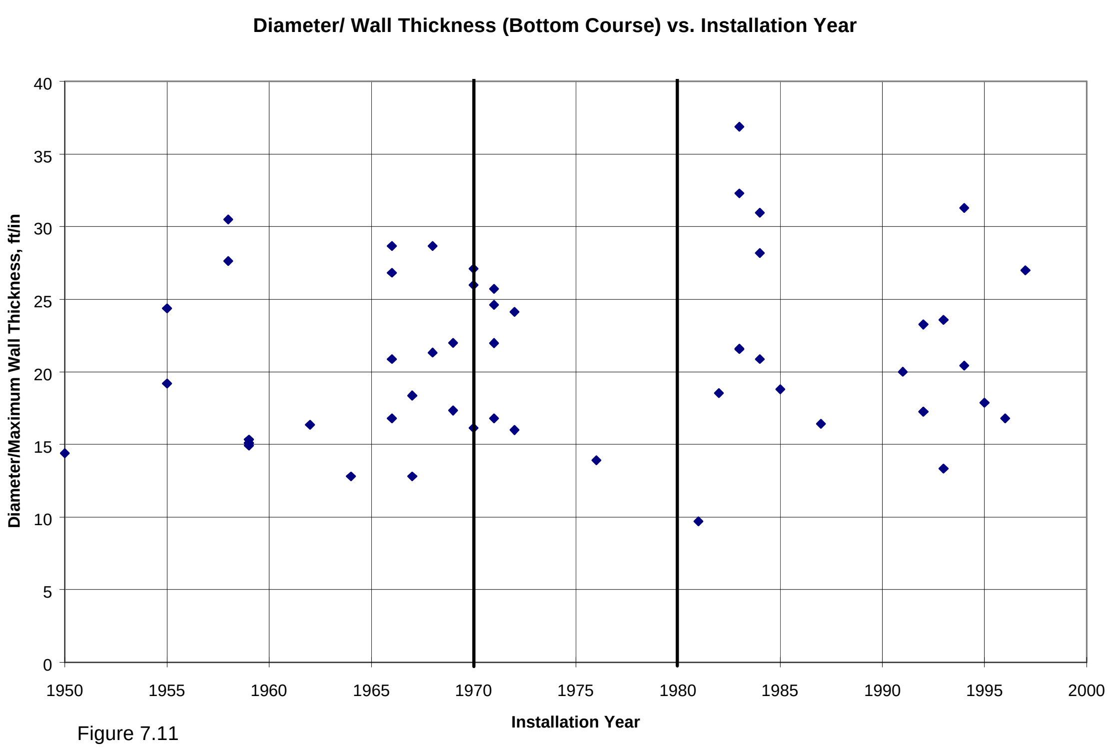


Figure 7.11

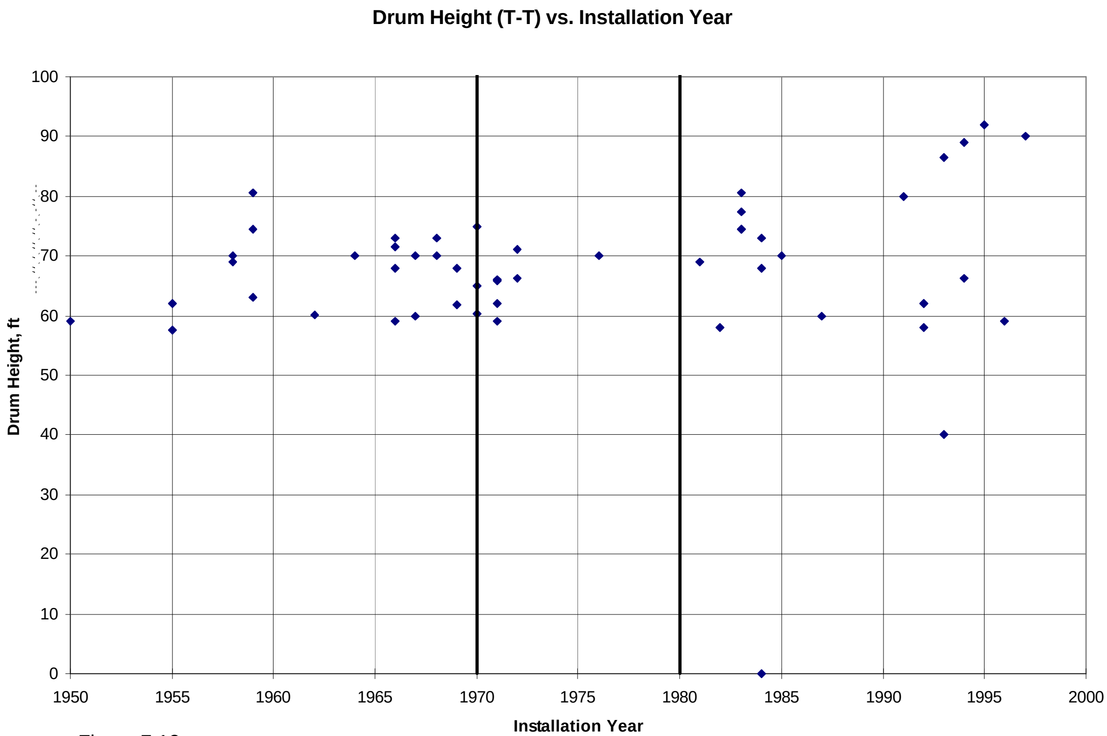


Figure 7.12

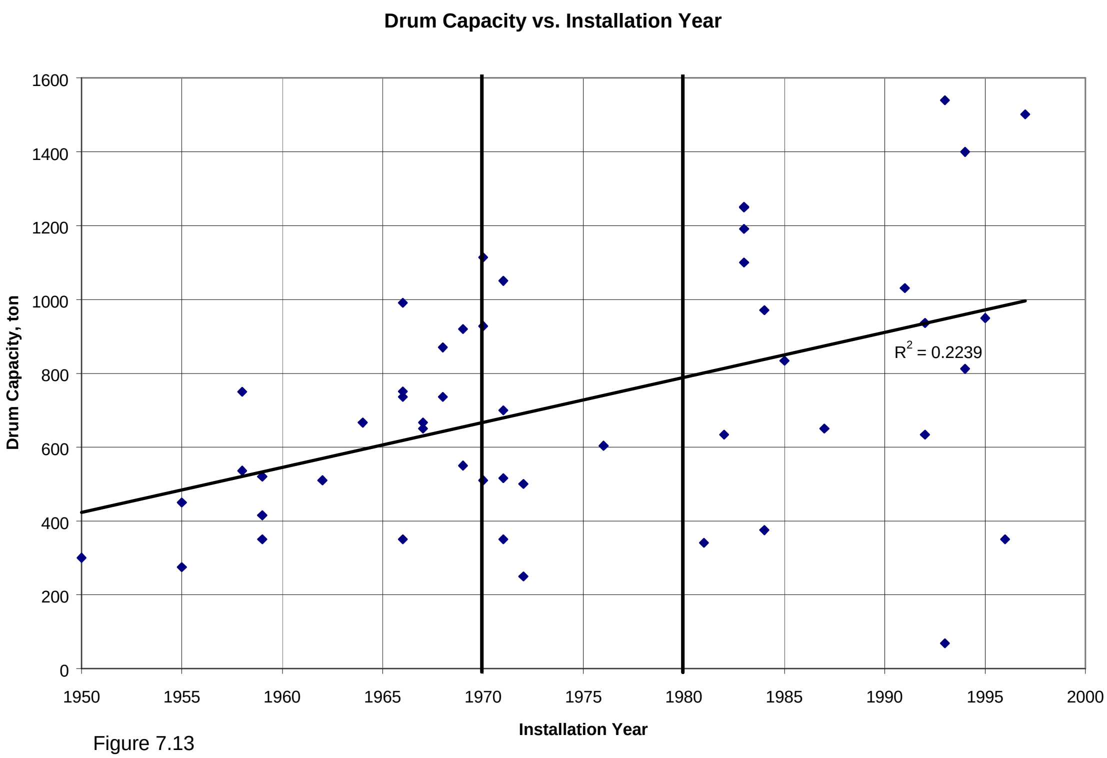


Figure 7.13

8.0 Materials and Design Compared to Drum Cracking Experience

8.1 SHELL MATERIALS

The role of materials and design parameters and its influence on cracking experience was investigated and are shown in Figures 8.01 to 8.08. Frequency distribution graphs of cycles until the first through wall crack versus number of surveys and percent of surveys are given in Figures 8.01a and 8.01b. Figures 8.01c and 8.01d show similar graphs comparing cycles until the first through wall crack versus the number of drums. These two sets of graphs show the performance of each material group.

The bar charts include all surveys or drums that are now a given age or have survived a given range of cycles. The line graphs below the bar charts show the percentage of surveys or drums.

Comparing the results of the two sets of graphs show that there was not much difference in comparing results per survey versus comparing results per drum.

There appears to be a rise in the number of surveys and drums that experienced through wall cracking around 3000 cycles for both C-Mo and Cr-Mo drums. Carbon steel drums see a similar rise around 5000 cycles. Carbon steel drums show a dramatic increase (100%) in percent of drums that have experienced a through wall crack after 7000 cycles. However, the number of drums in this last group is small, consisting of only two surveys (6 drums).

Chrome Moly drums show an increase after 6000 cycles where over 60% of the drums report through wall cracking. There was not any data submitted on older Cr-Mo drums.

Figures 8.01e and 8.01f show the different material groups plotted against the cycles to the first through wall crack. The black diamonds indicate reported cycles to the first through wall crack. The open squares in Figure 8.01f plot the present number of cycles on drums that have not cracked. Only drums with 4,000 cycles or more were plotted with the open squares.

Not included in these graphs is one vessel of 1-Chrome material at approximately 2700 cycles that has experienced cracking, but not through wall cracking. Also not included is a 2¼-Chrome material drum that experienced a non-through wall crack at approximately 1070 cycles (after submission of the survey).

Table 8.01 gives the average, minimum, and maximum cycles for surveys reporting cracked and non-cracked drums.

Table 8.01
Cycles to First Through Wall Crack

Material	Average First Through Wall Crack	Minimum Cycles to First Through Wall	Maximum Cycles without Crack
Carbon Steel	5968	3650	5749
Carbon ½ Moly	3968	1286	(9386)*
Chrome Moly	3570	2025	(5994)*

* - note, still operating without a through wall crack.

These results indicate that there is not much difference between the various drum materials. There appears to be a slight benefit with the C ½ Mo drums as seen in Figures 8.01b and 8.01d. However, Figures 8.01a and 8.01c show that the population of CS and Cr-Mo drums is small.

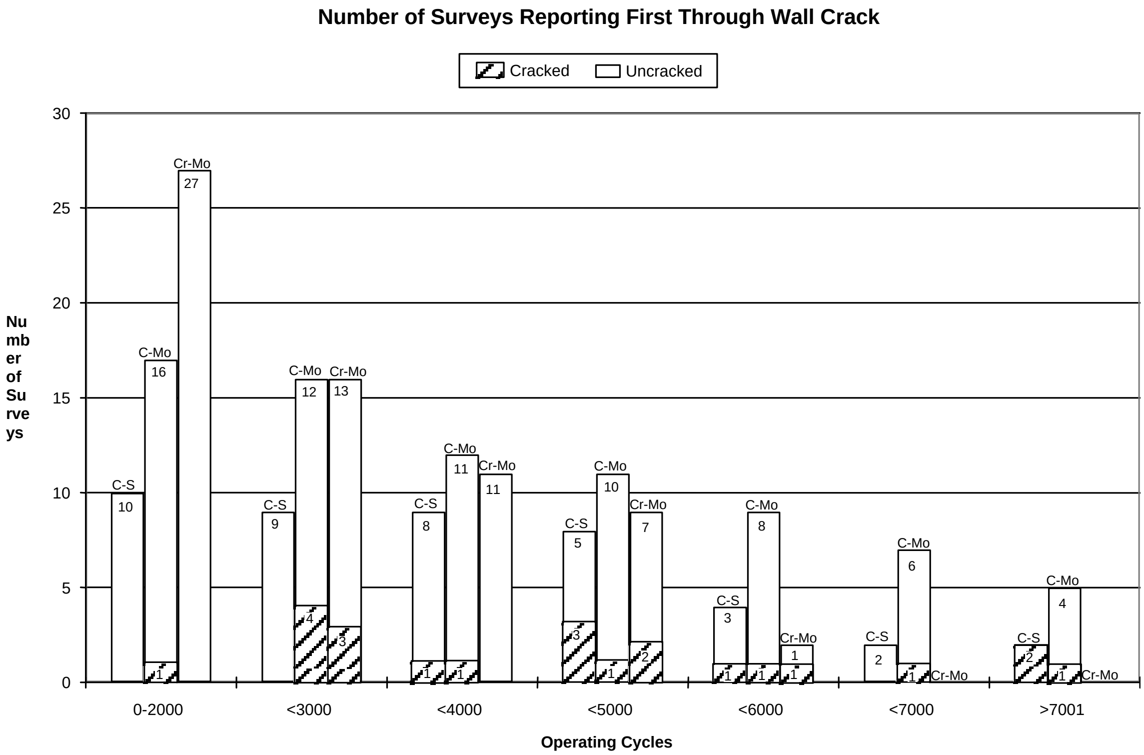


Figure 8.01a

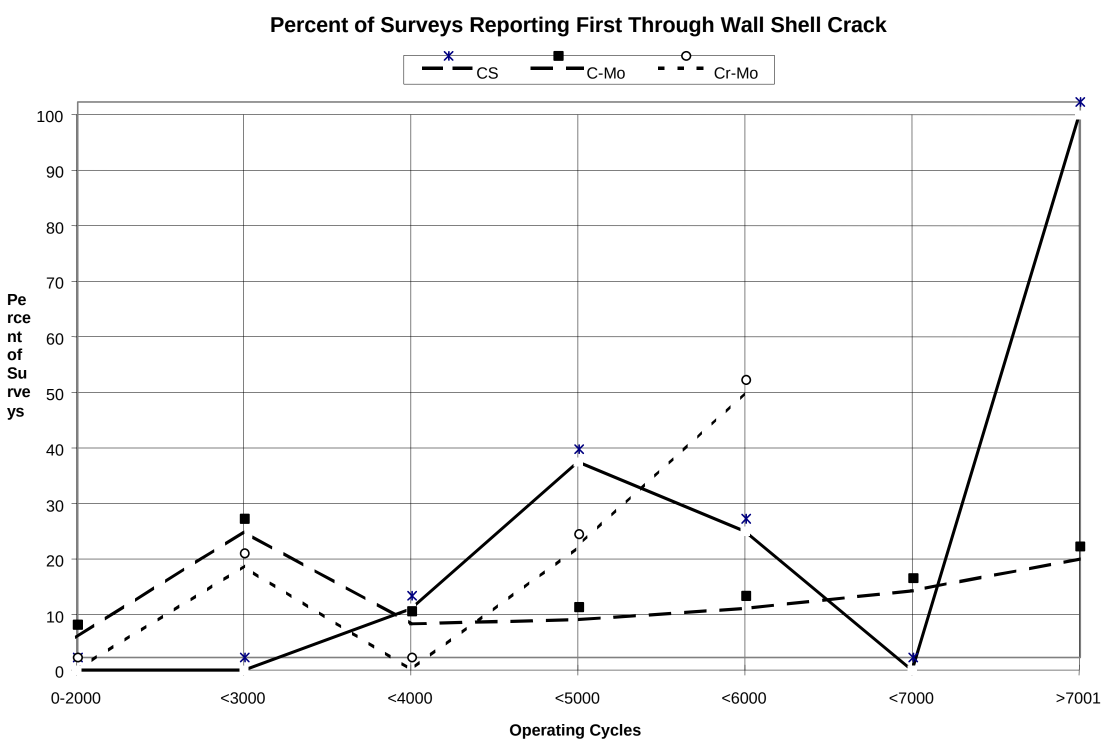


Figure 8.01b

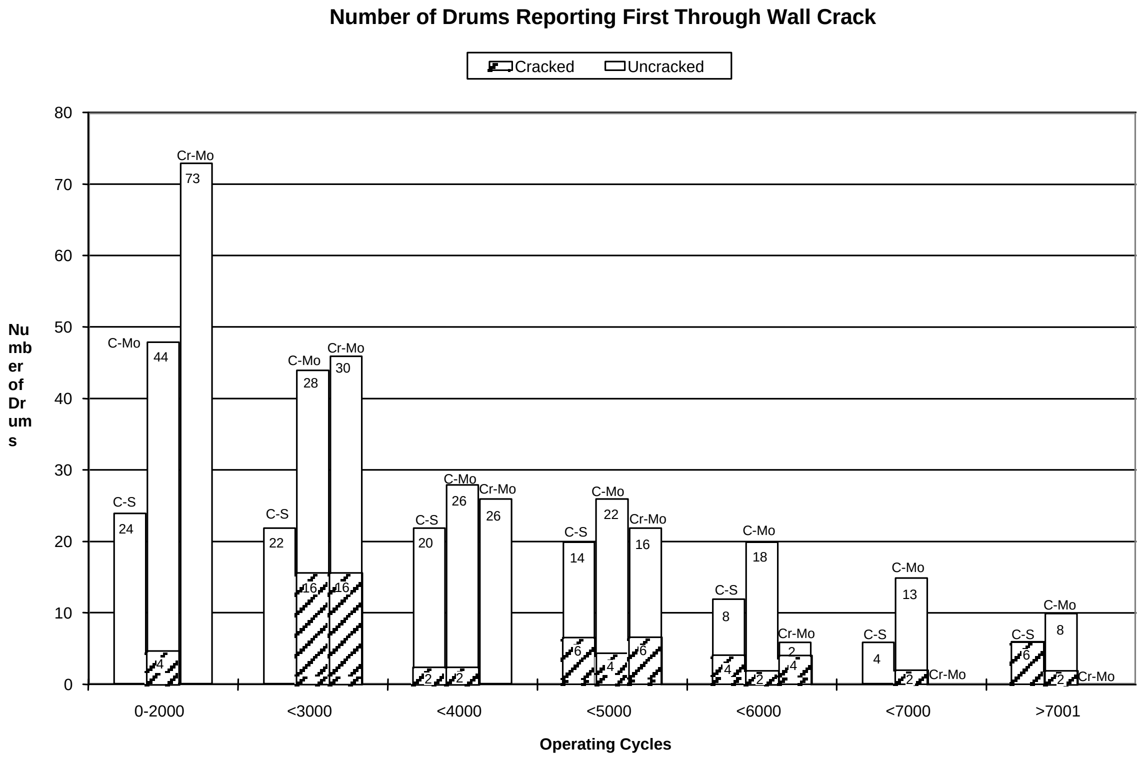


Figure 8.01c

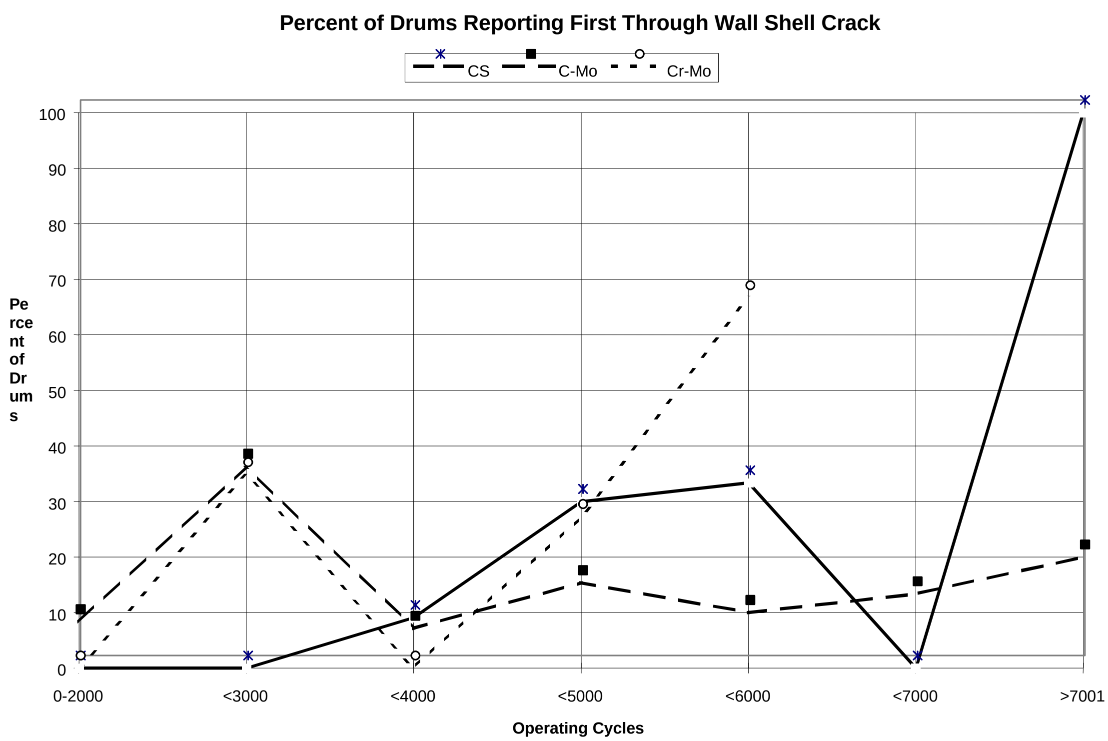


Figure 8.01d

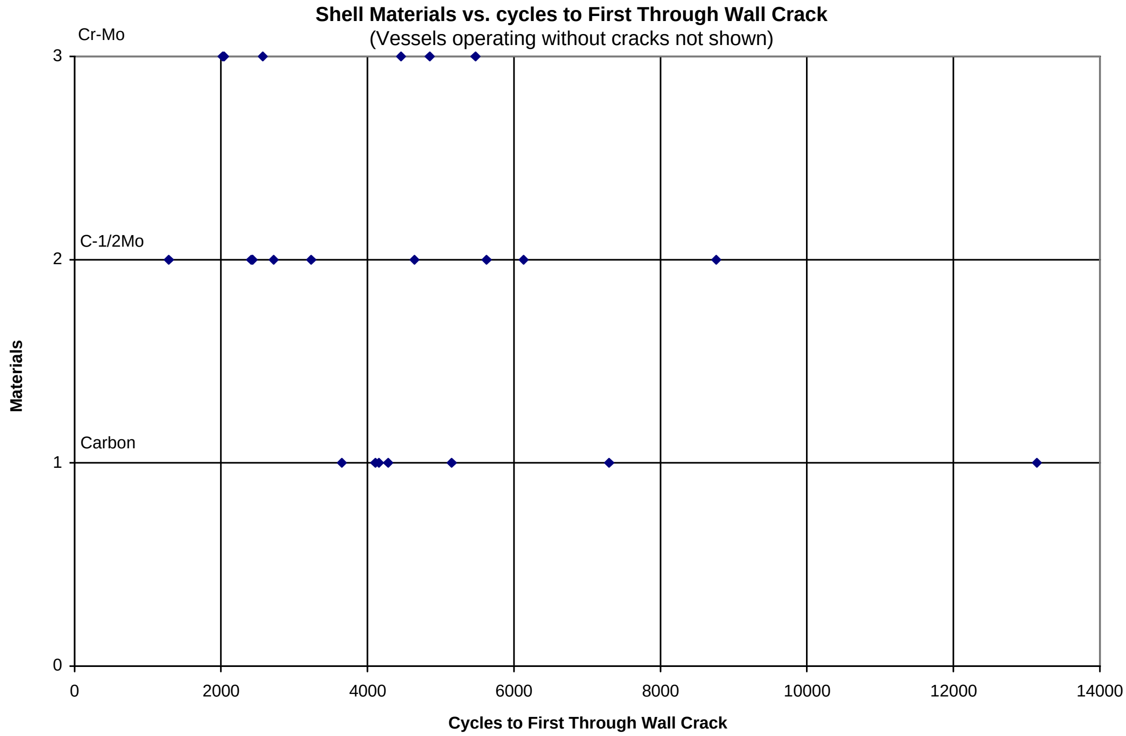


Figure 8.01e

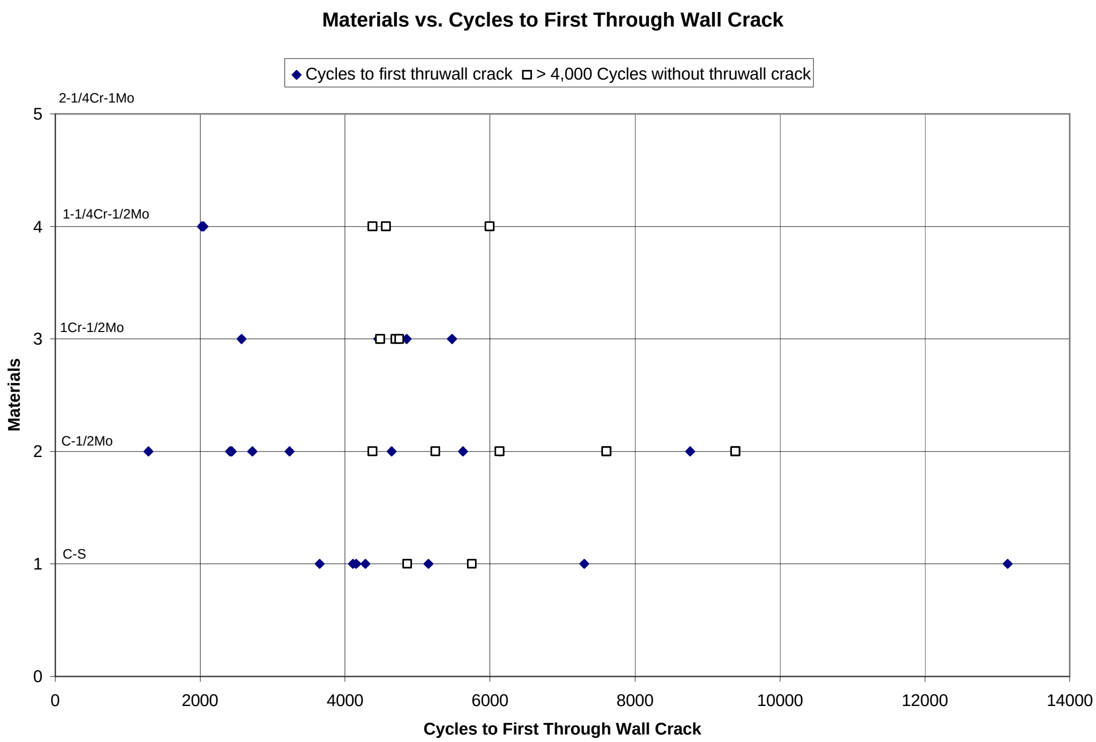


Figure 8.01f

8.2 DRUM DESIGN DIMENSIONS VS. CRACKING

The roles of materials and dimensional design parameters and its influence on cracking experience was also investigated and are shown in Figures 8.02 to 8.08.

As stated before, trend lines were included in the graphs when possible. Straight lines were plotted as a linear array while the curved lines were plotted as a second order polynomial function (parabolic). The "R^2" value is also plotted to show how well the curve fit the data. Only the black diamond data points were used to plot trends. The open square data points are for reference information. Separate trend lines for each group of drum materials was also included for several design parameters. The type of line used was based on which function (linear or polynomial) gave the best R^2 value. The larger the R^2 value, the better the fit, the best fit approaches a value of 1.

A graph of drum diameter versus cycles until the first through wall crack is shown in Figure 8.02. Trend lines for each material group were inserted to show a general trend of smaller diameter drums having higher number of cycles to the first through wall crack. The data on this is also affected by age bias since larger diameter drums are relatively new design and there is not much history yet.

Figure 8.03 shows that there is almost no trend towards higher number of cycles for increasing wall thickness. Figure 8.04 shows a diameter over thickness value versus cycles until the first through wall crack.

Survey question 5.25 asked the respondent to estimate the total number of cracks that the vessel had to date. These answers ranged from 0 to 300+ cracks. An upper cut-off of 100 cracks was used so there would be some spread to the data in low values. Figure 8.05 shows the values plotted of number of cracks versus operating cycles for the five different materials. This is also shown grouped by alloys in a bar chart in Figure 8.06.

The number of through wall cracks for vessels with less than 11,000 cycles is shown in Figure 8.07. Figure 8.08 shows this data in a three dimensional bar chart grouped by alloys.

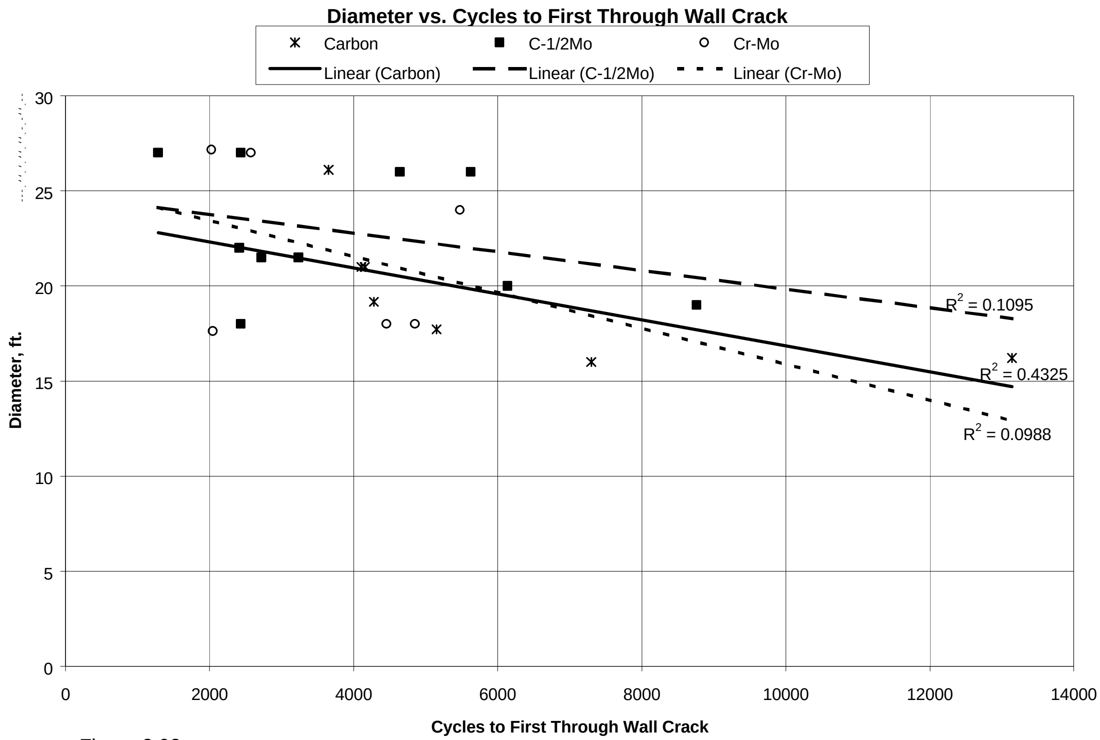


Figure 8.02

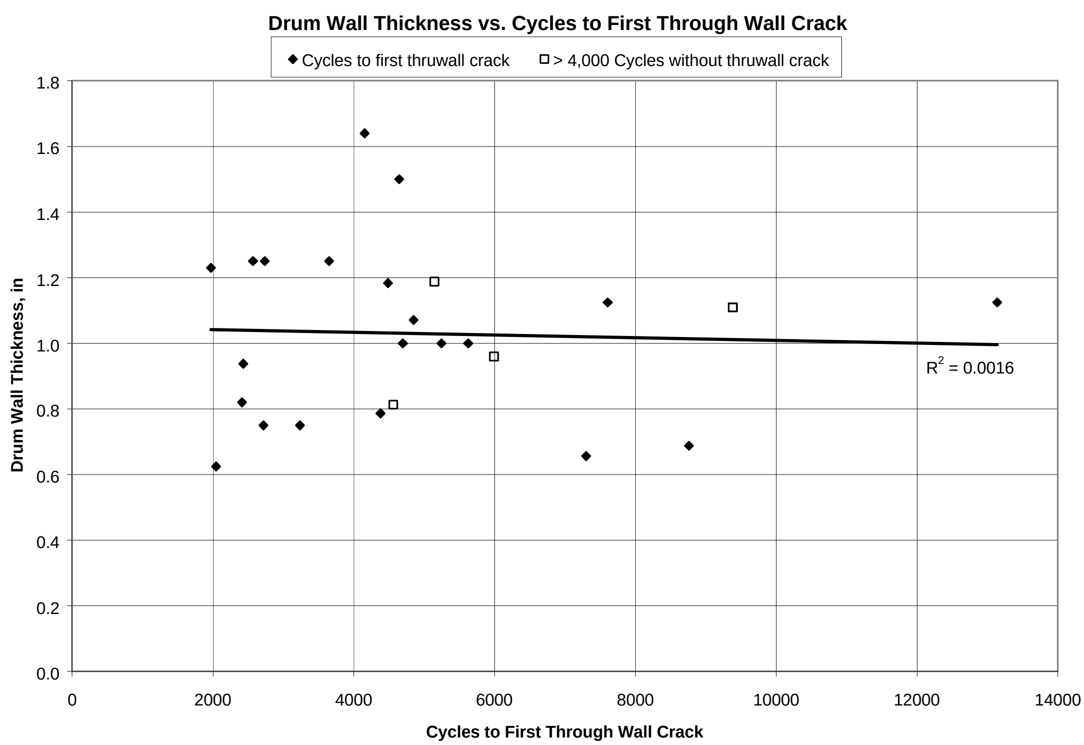


Figure 8.03

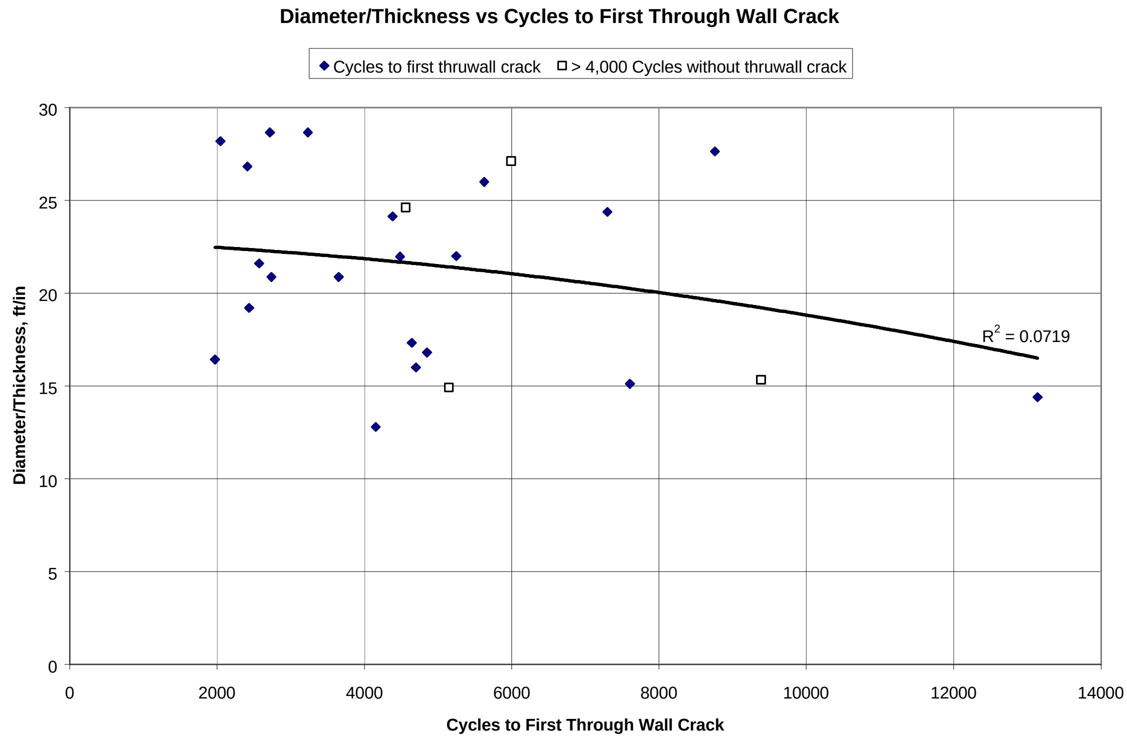


Figure 8.04

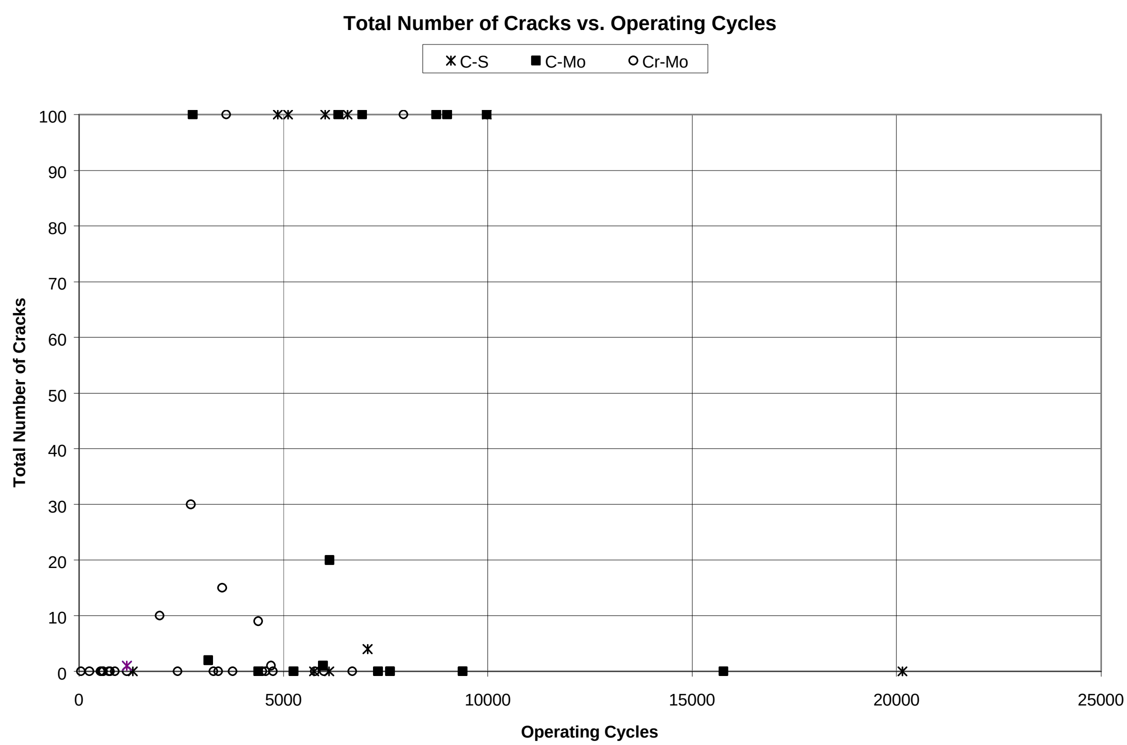


Figure 8.05

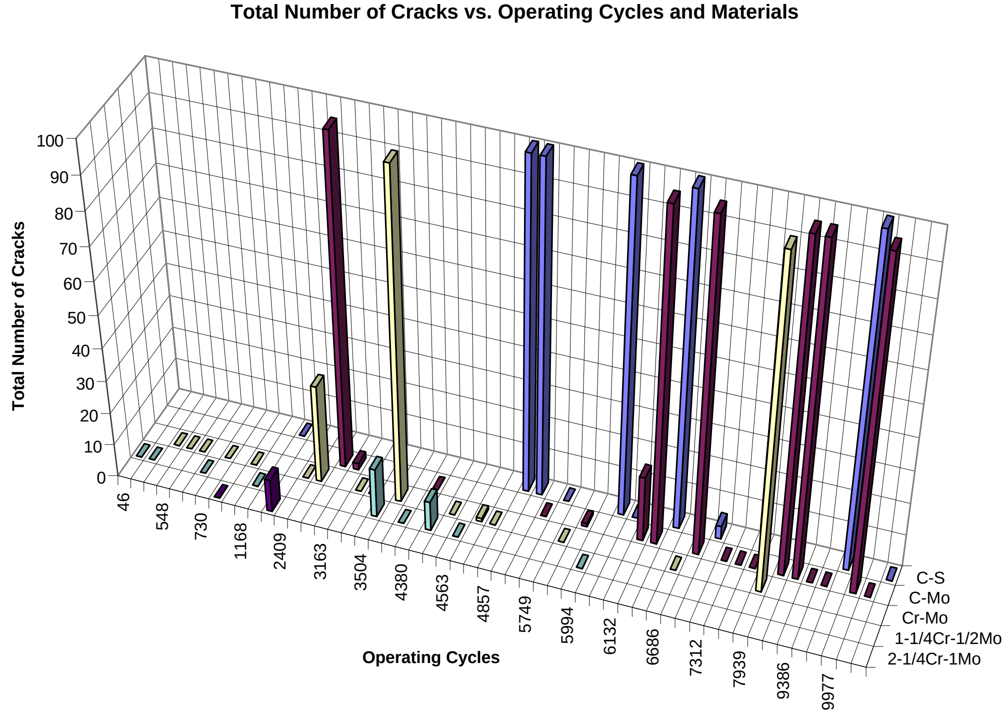


Figure 8.06

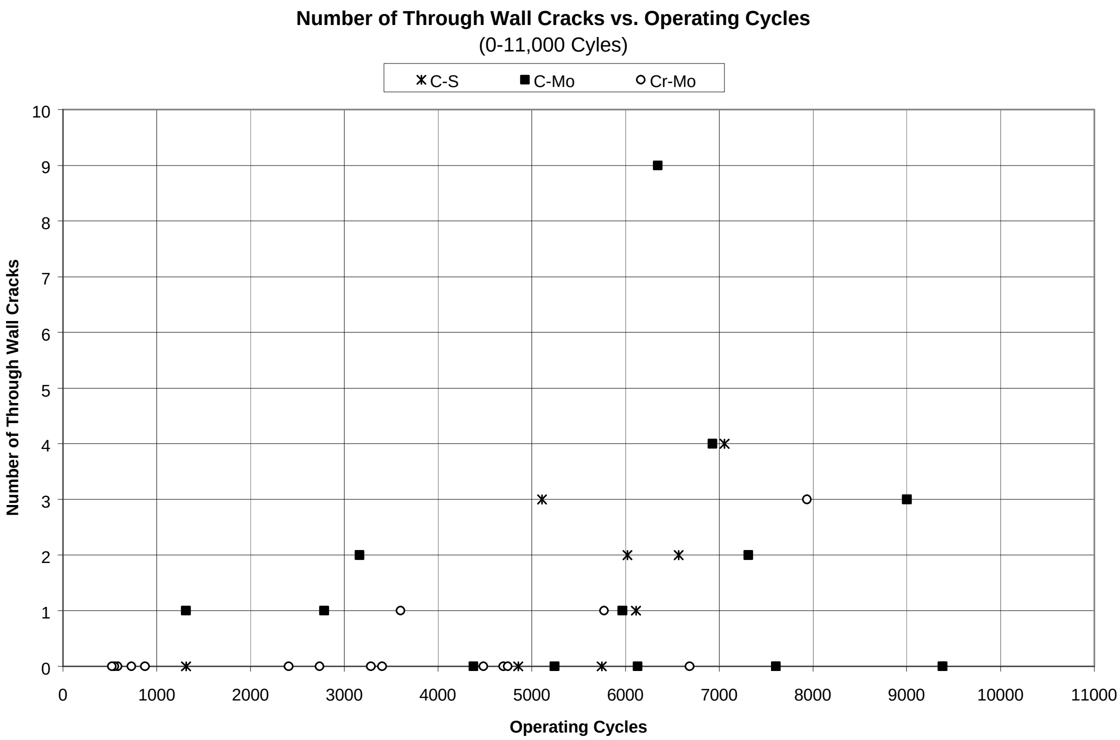


Figure 8.07

Number of Through Wall Cracks vs. Operating Cycles and Materials

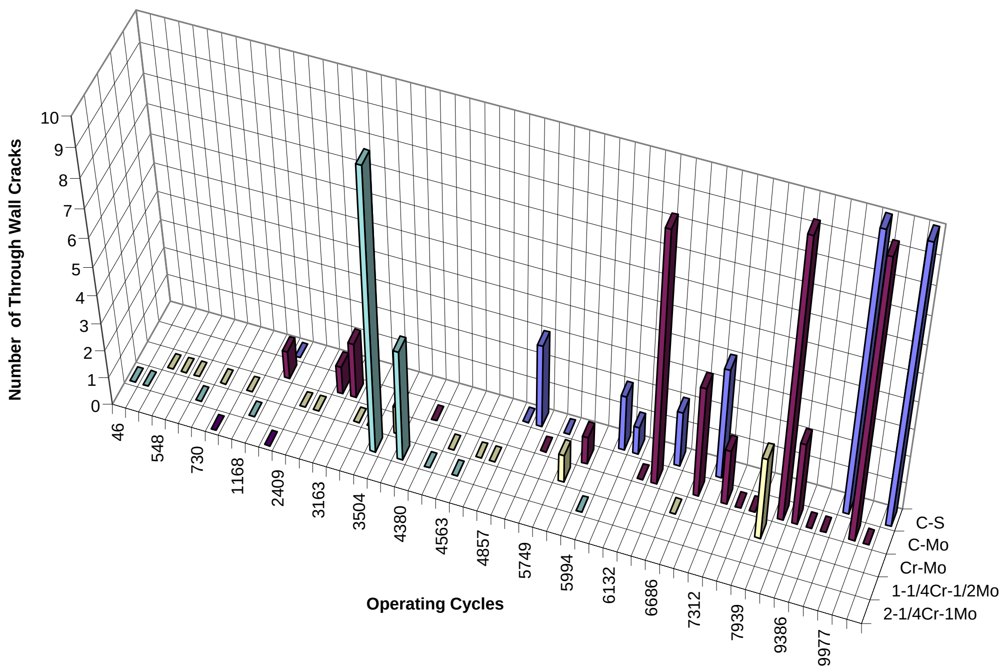


Figure 8.08

9.0 Material and Design Compared to Drum Bulging Experience

In a similar manner as in Section 8, the role of materials and design parameters and its influence on bulging experience was investigated and are shown in Figures 9.01 to 9.09. Frequency distribution graphs of cycles until the first bulge versus number of surveys and percent of surveys are given in Figures 9.01a and 9.01b. Figures 9.01c and 9.01d show similar graphs comparing cycles until the first bulge versus the number of drums. These two sets of graphs show the performance of each material group.

As with the cracking data, the results of the two sets of graphs show that there was not much difference in comparing results per survey versus comparing results per drum.

It appears that bulging generally occurs earlier than cracking. There appears to be a rise in the number of surveys and drums that experienced bulging around 2000 cycles for both C-Mo and Cr-Mo drums as compared to 3000 cycles for the cracking correlation. Carbon steel drums see a similar rise around 3000 cycles as compared to 5000 cycles observed with cracking. As with cracking, Carbon steel drums show a dramatic increase (100%) in percent of drums that have experienced a through wall crack after 7000 cycles.

Chrome Moly drums show an increase after 5000 cycles where almost 60% of the drums report bulging.

Table 9.01 gives the average number of cycles until the first bulge, along with minimum and maximum cycles.

Table 9.01

Cycles to First Bulge

(Cycles to First Through Wall Crack for Reference)

Material	Average Number of Cycles to First Bulge	Minimum Number of Cycles to First Bulge	Maximum Number of Cycles w/o Bulge
Carbon Steel	3023	183	7057
Carbon ½ Moly	2504	346	(9386)*
Chrome Moly	2978	1286	(4745)*
Material	Average First Through Wall Crack	Minimum Cycles to First Through Wall	Maximum Cycles without Crack
Carbon Steel	5968	3650	5749
Carbon ½ Moly	3968	1286	(9386)*
Chrome Moly	3570	2025	(5994)*

* - note, still operating without a bulge.

These results indicate that there is not much difference between the various drum materials. There appears to be a slight benefit with the Cr-Mo drums early in life (up to 4000 cycles) as seen in Figures 9.01b and 9.01d. However, this difference is small and appears to be offset by the large increase in percent of bulging of drums at 5000 cycles.

9.1 DRUM DESIGN DIMENSIONS VS. BULGING

The roles of materials and dimensional design parameters and its influence on bulging experience was also investigated and are shown in Figures 9.02 to 9.08. The black diamonds indicate reported cycles to the first bulge. The open squares in Figures 9.01e through 9.08 plot the present number of cycles on drums that have not bulged. Only drums with 4,000 cycles or more were plotted with the open squares.

The trend lines included in this section are similar to those used before in Sections 7 and 8. Only the black diamond data points were used to plot trends. The open square data points are for reference information. The larger the R^2 value, the better the fit, the best fit approaches a value of 1.

Graphs of drum diameter, wall thickness, and D/t ratios versus cycles until the first bulge are shown in Figures 9.02-9.04. Trend lines for each material group indicate that there is not a correlation trend for any of these parameters.

The same is true in Figures 9.07 & 9.08 where number of bulges were tested for correlation.

The occurrence of bulging and cracking was compared to the shell course number. Courses were numbered from the bottom up, i.e., Course 1 is welded to the bottom cone. Figure 9.09 shows the frequency of occurrence versus shell course. It was found that bulging occurred in Courses 1 through 7 and cracking occurred in Courses 1 through 6. The most common occurrence for both bulging and cracking was in Courses 3, 4 and 5.

Depth of bulging (radial distance) was examined and compared on a frequency basis and shown in Figure 9.10. Maximum and average bulge depth were plotted based on frequency per survey. One and two inch deep bulges were the most common average depth while a three inch bulge was the most common maximum depth.

9.2 CLADDING PERFORMANCE

Performance of cladding was also investigated based on the type of cladding attachment. Figure 9.11 and the table below (Table 9.02) indicate that roll bond cladding performed the best with the lowest number of occurrences of cladding disbonding while having the highest number of uses. Disbonding only occurred in drums with bulging.

Disbonding rates were higher for both explosion bonding and plug welding as compared to roll bond cladding. However, the sample size was relatively small and the spread in a true percent expected occurrence of failure is difficult to predict based on this limited data set.

Table 9.02

Occurrence of Disbonding

Type of Clad Attachment	Total Number of Surveys	Number of Disbonded Cladding	Percent Disbond
Plug Weld	5	2	40%
Explosion Bond	9	4	44%
Roll Bond	36	11	31%

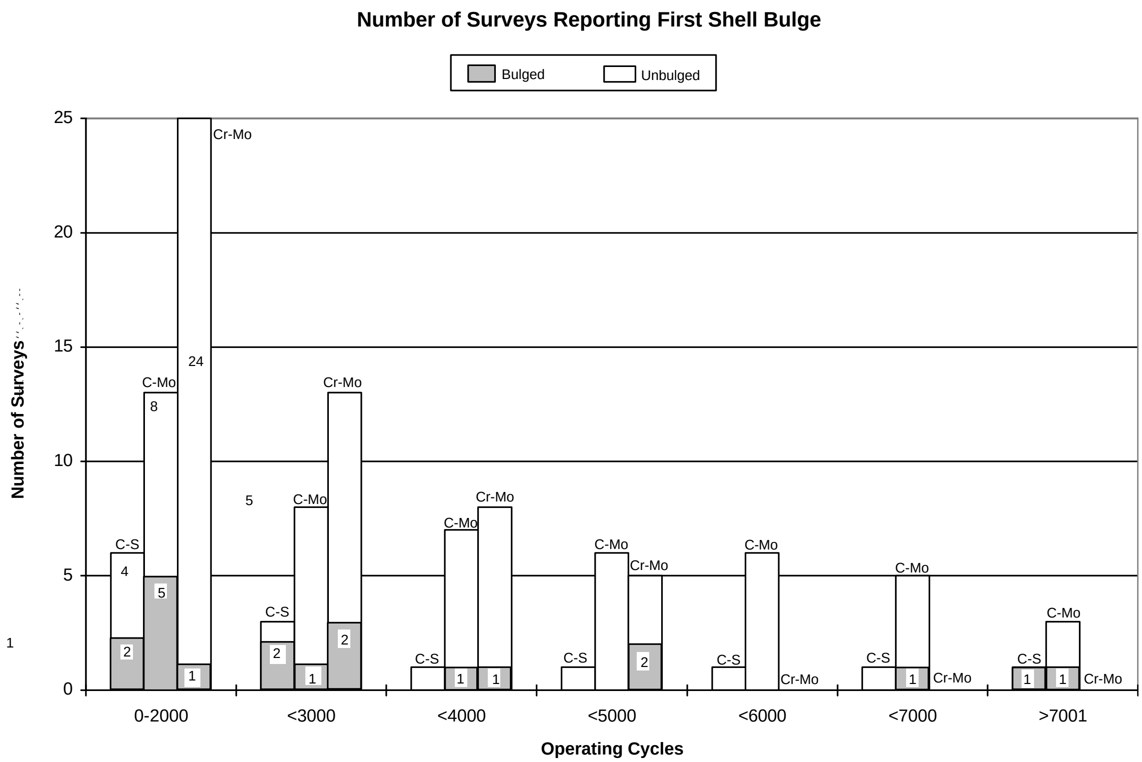


Figure 9.01a

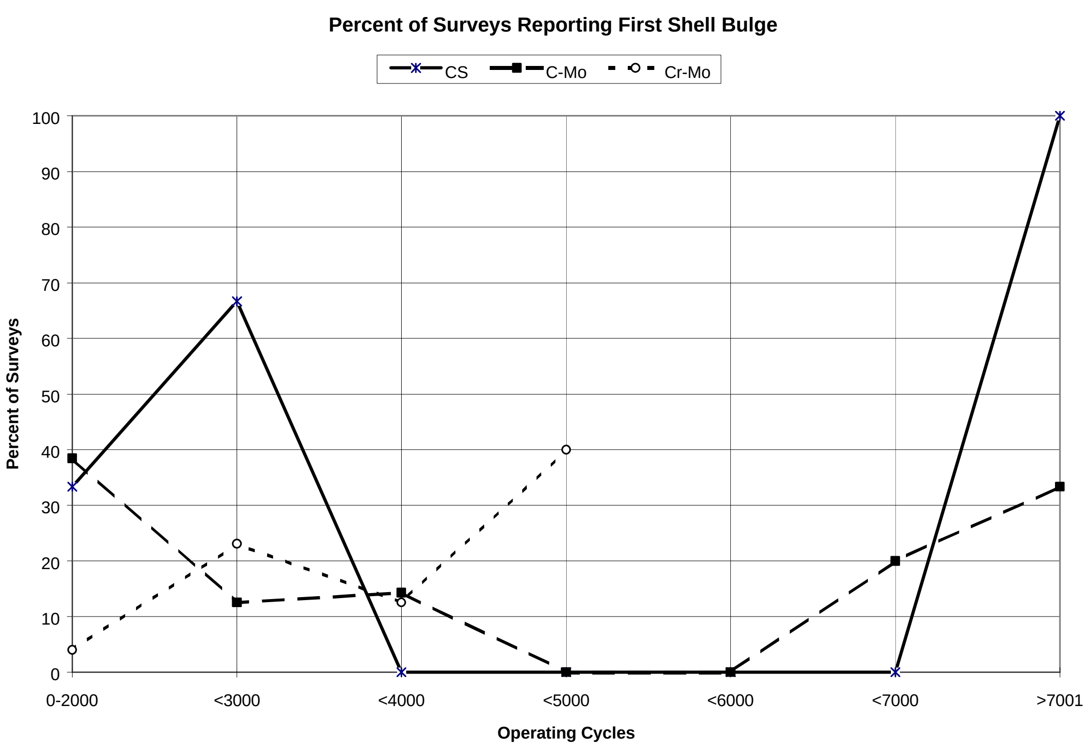


Figure 9.01b

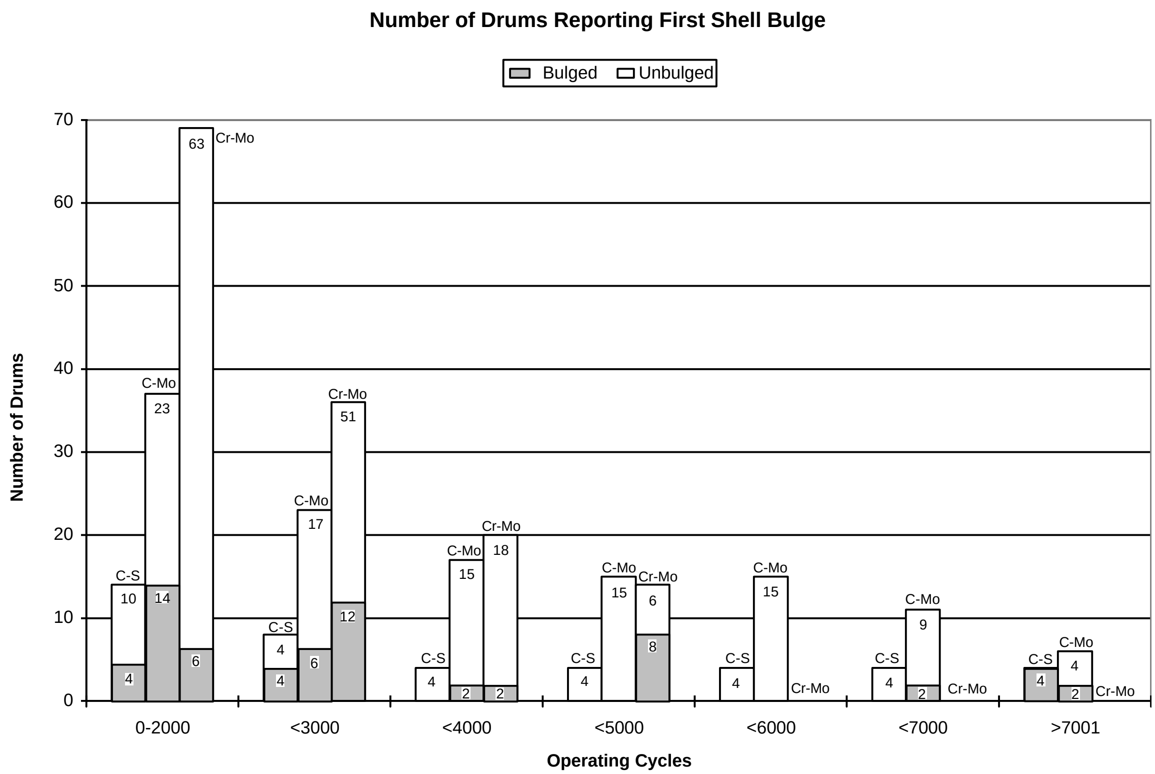
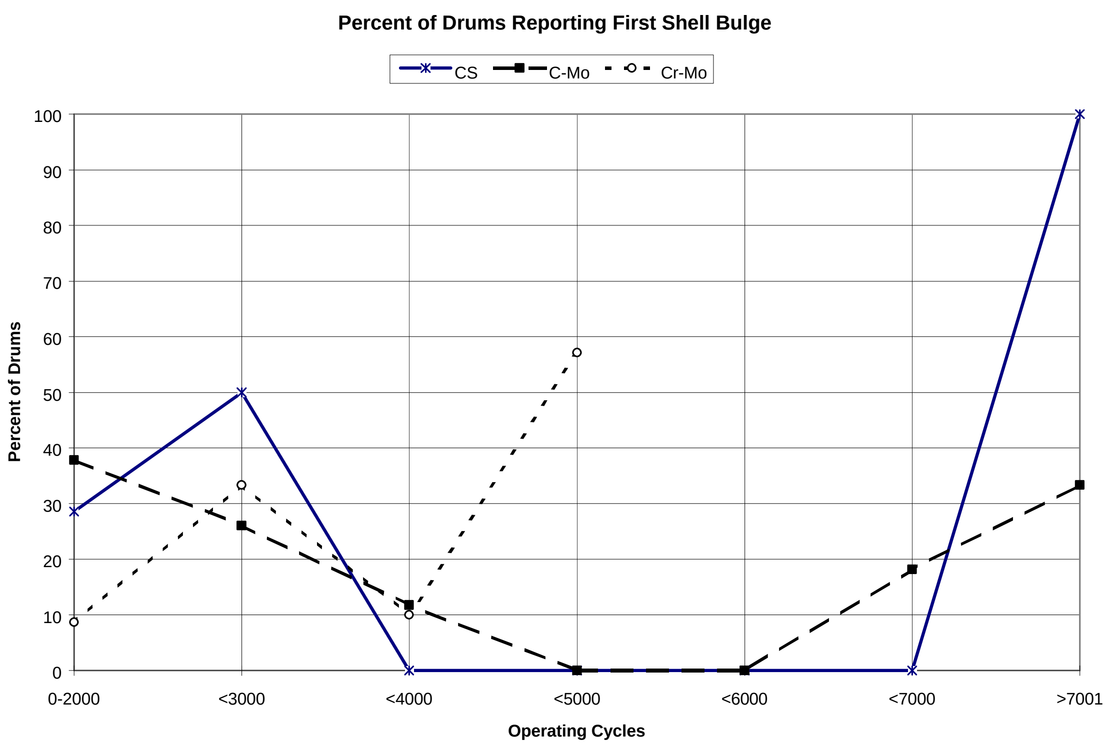


Figure 9.01c



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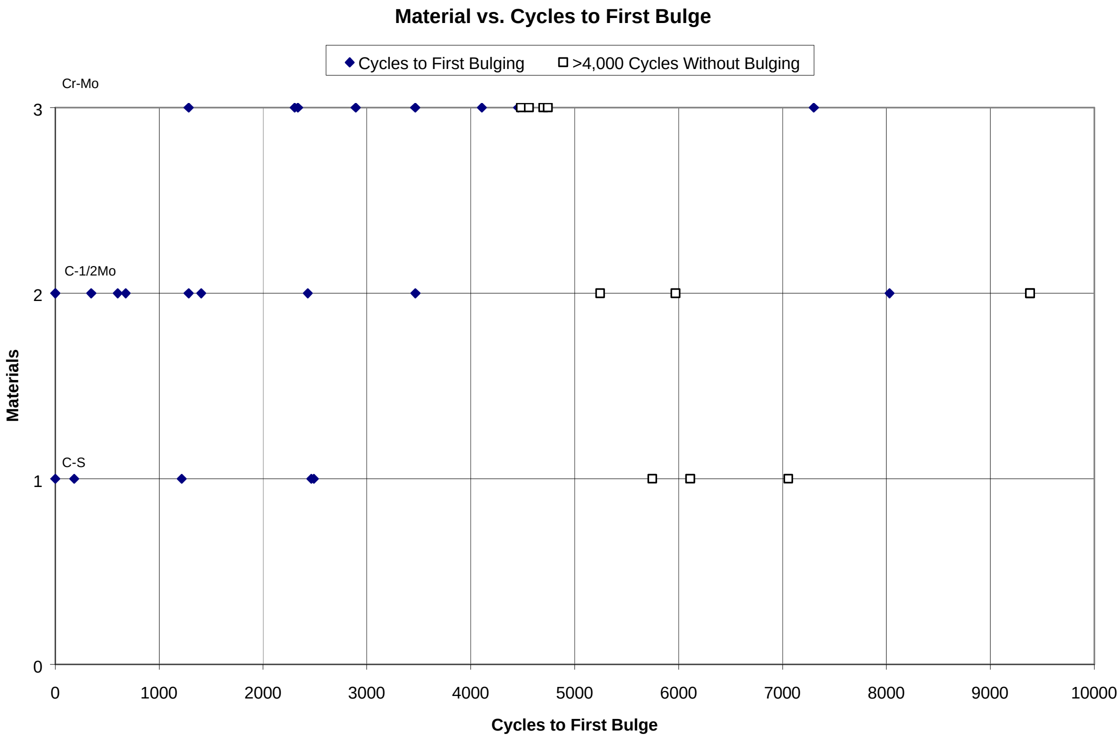
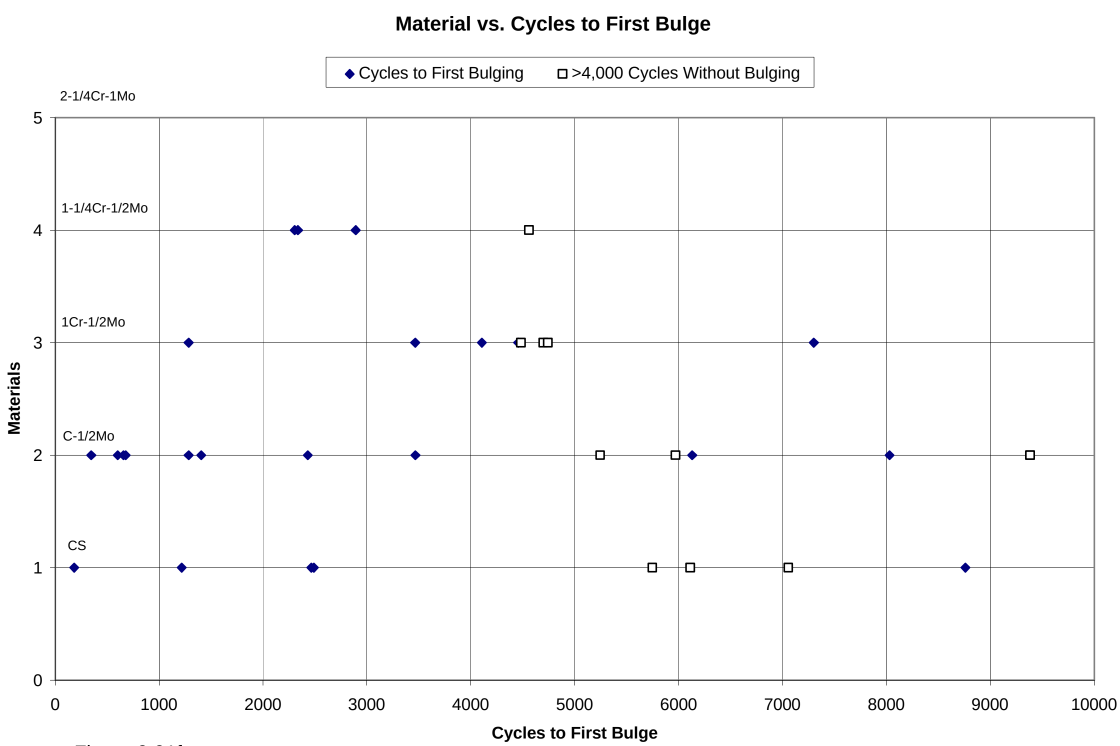


Figure 9.01e



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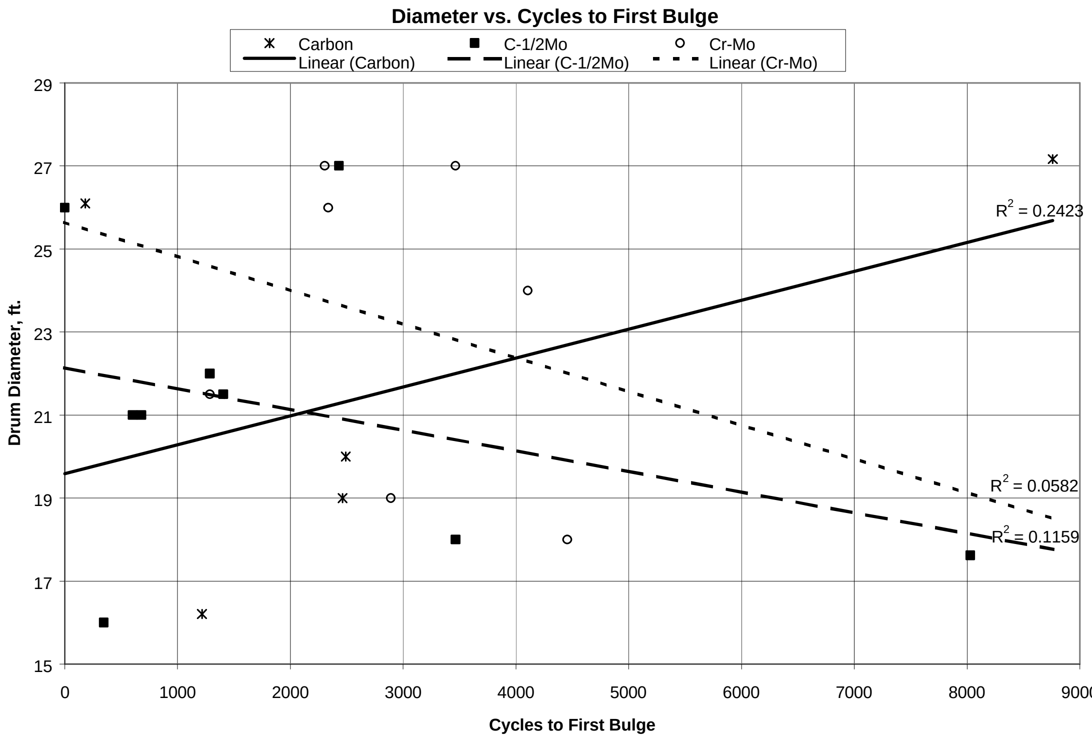

Figure 9.02

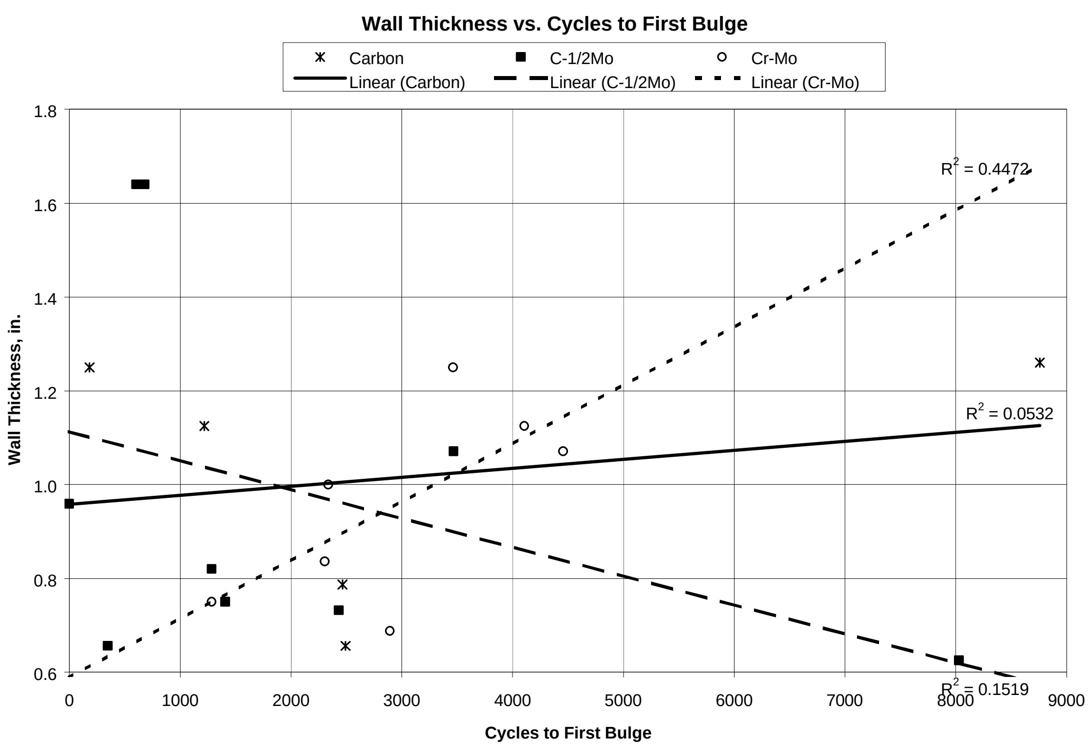

Figure 9.03

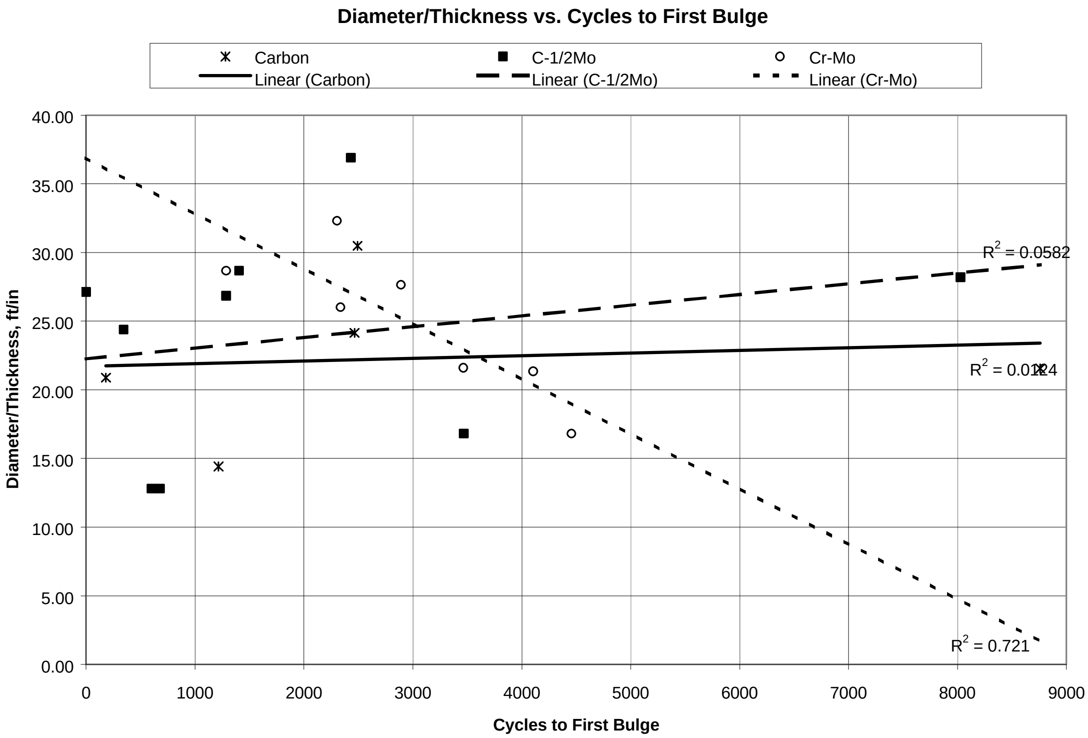

Figure 9.04

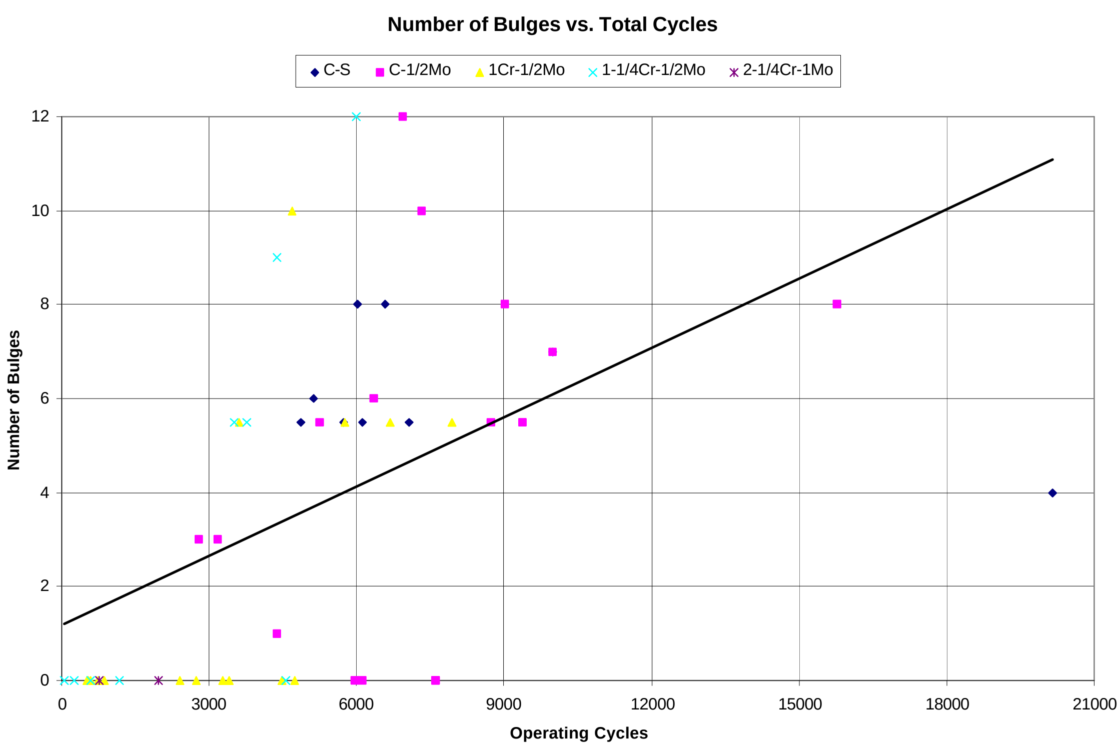

Figure 9.05

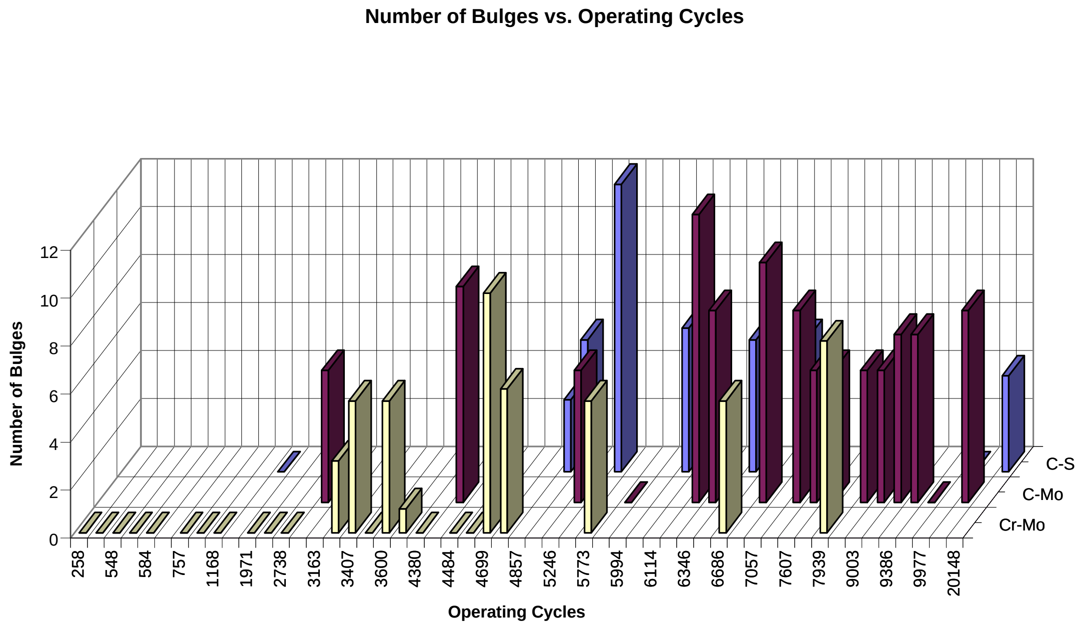

Figure 9.06

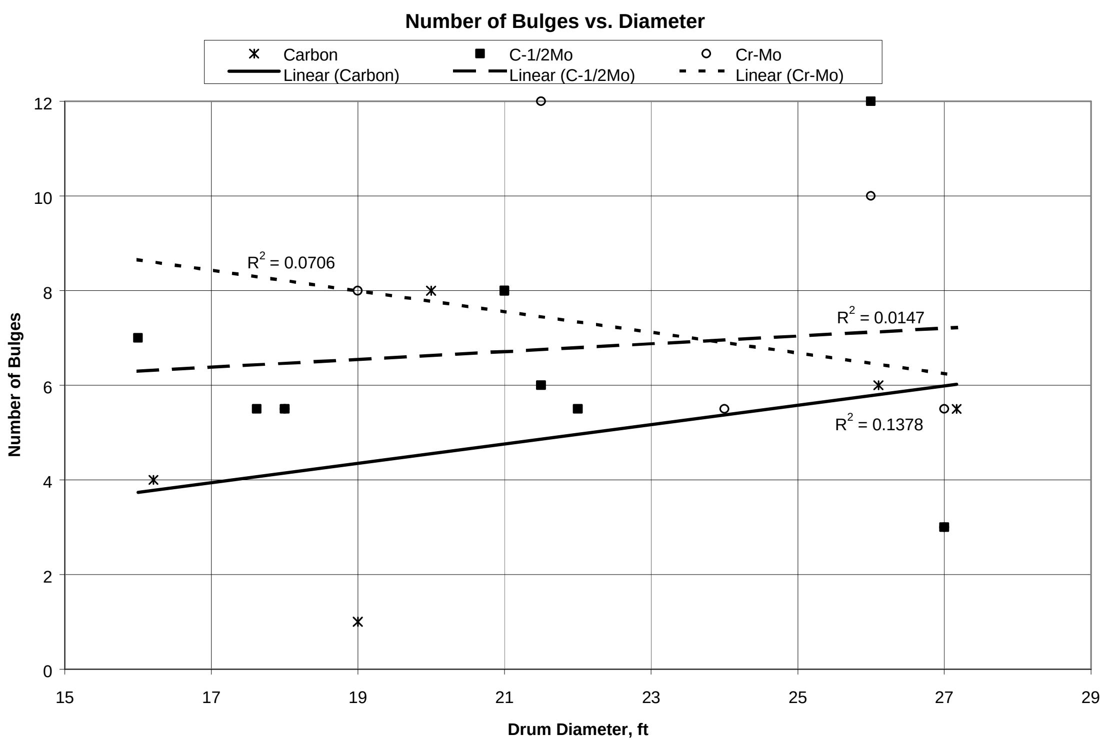

Figure 9.07

Number of Bulges vs. Diameter/Thickness

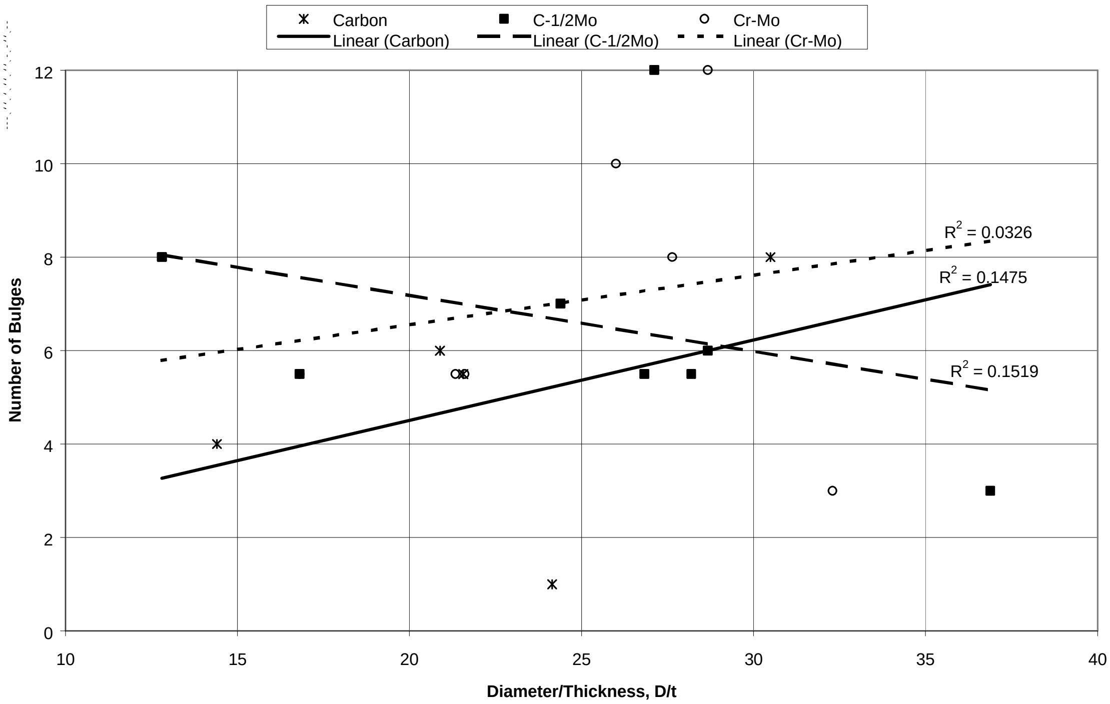

Figure 9.08

Histogram of Bulge and Crack Distribution

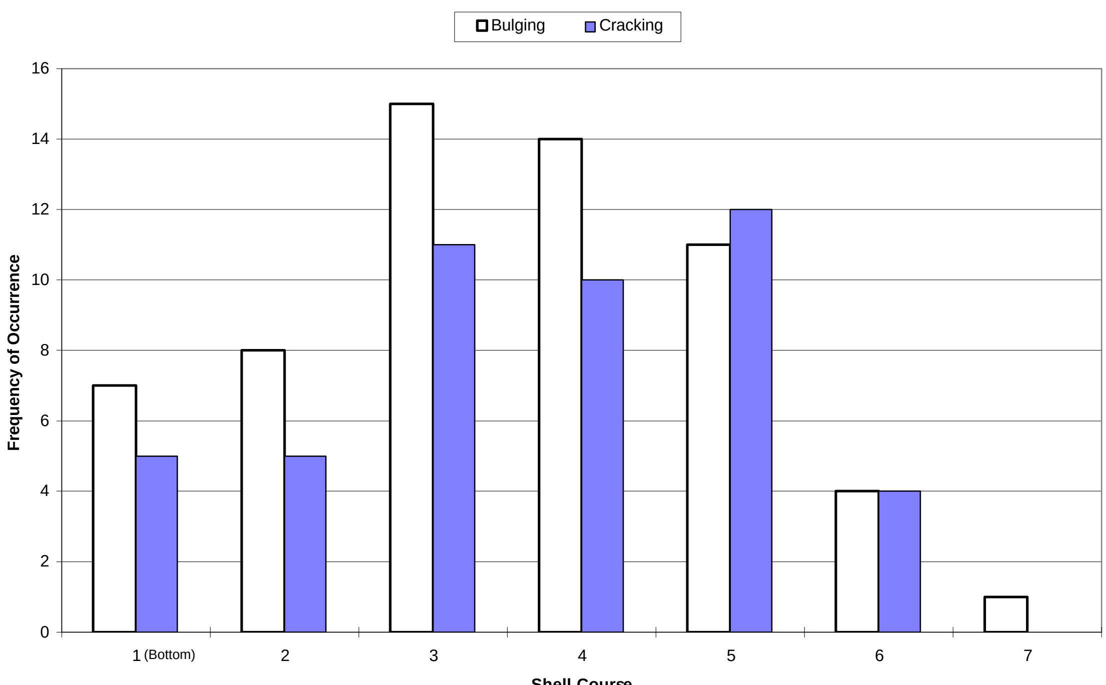

Figure 9.09

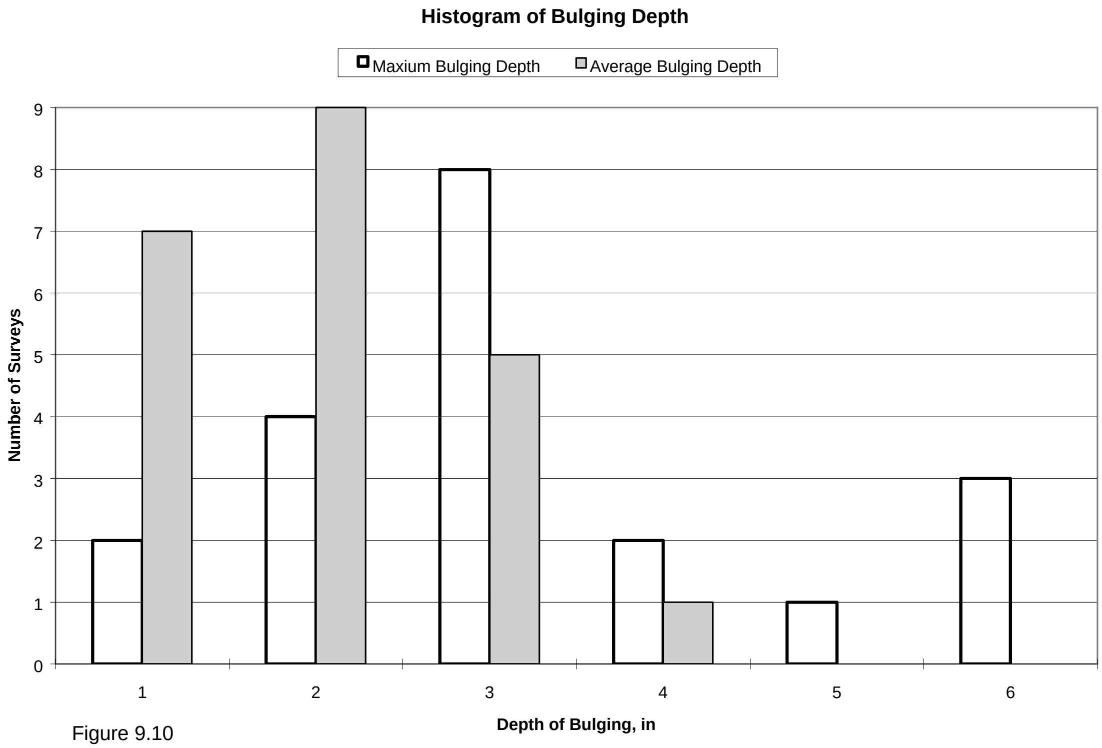

Figure 9.10

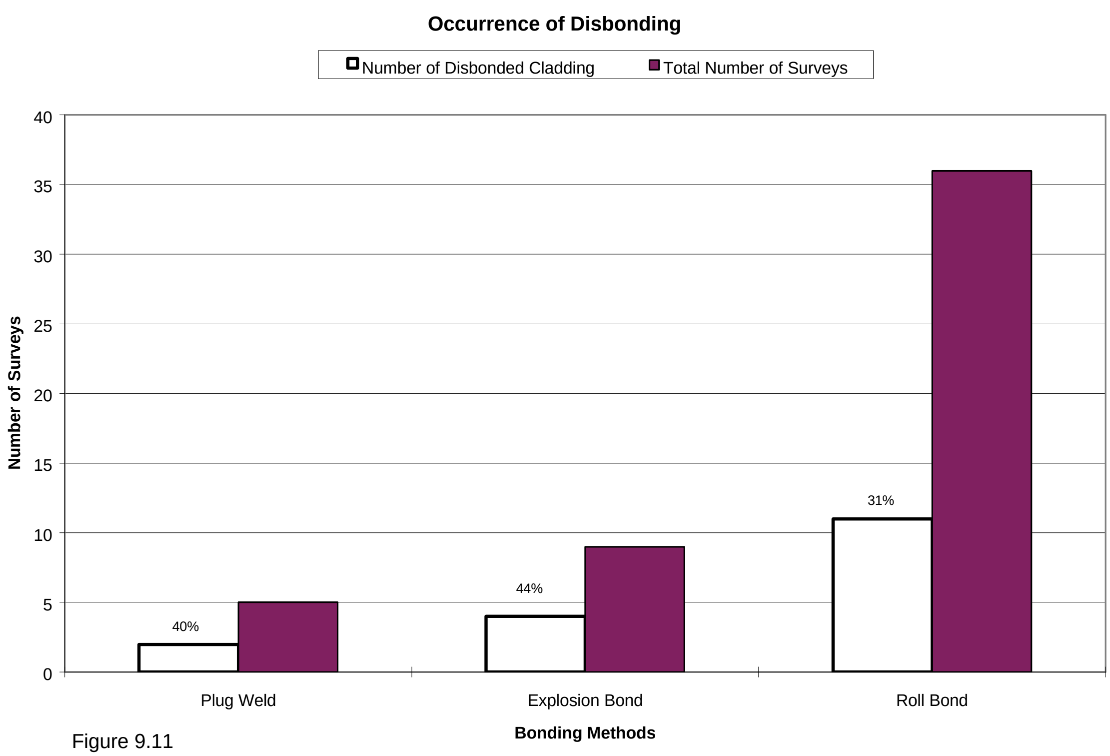

Figure 9.11

10.0 Skirt Deterioration Versus Materials and Design

Figure 10.01 shows the seven occurrences of skirt bulging. Six of these occurrences were carbon steel material and one was in 1 Chrome material.

Figure 10.02 shows the trends for different materials and the number of cycles to the first skirt crack. In this graph the empty circles represent the number of cycles accrued at skirt replacement. Figure 10.03 shows the three groups of materials plotted data for skirts with cracks and without cracks.

From the data shown in Figures 10.02 and 10.03, there is no clear advantage of one material over another.

Figure 10.04 has a variable of skirt thickness. No direct correlation with skirt thickness was seen in this chart. A correlation was indicated when comparing cycles to the first skirt crack versus calculated skirt compressive stress. A simplified value for skirt compressive stress was derived from skirt diameter, skirt wall thickness and drum design capacity in tons of coke. This value was compared to cycles to the first skirt crack. Figure 10.05 indicates somewhat of a trend of increasing skirt compressive stress increased the number of cycles to first skirt crack.

Skirt Bulging Status vs. Material and Operating Cycles

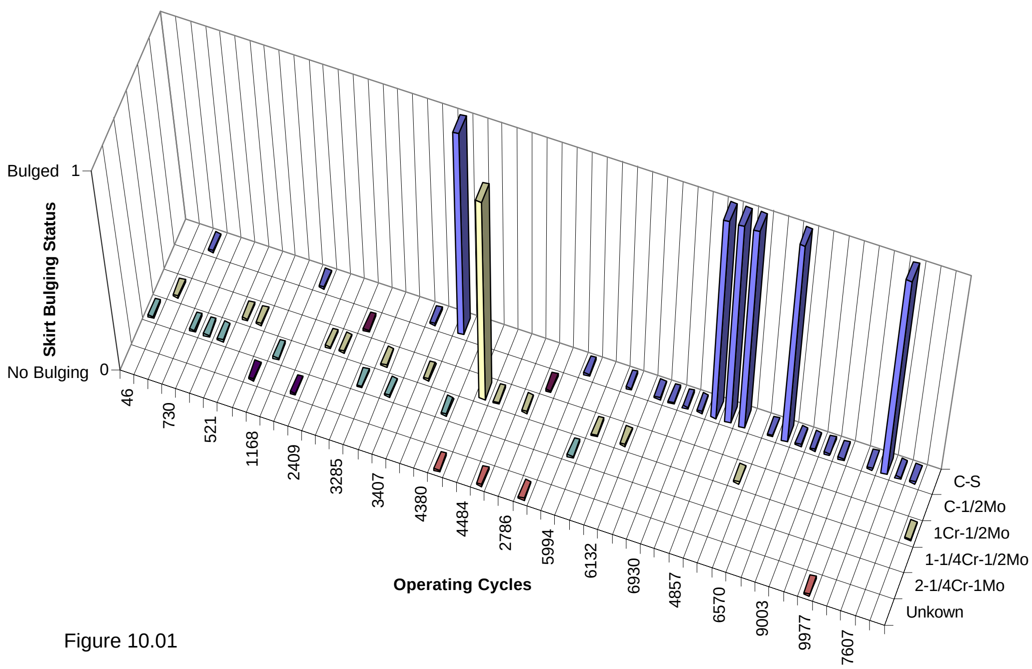

Figure 10.01

Material vs. Cycles to First Skirt Crack

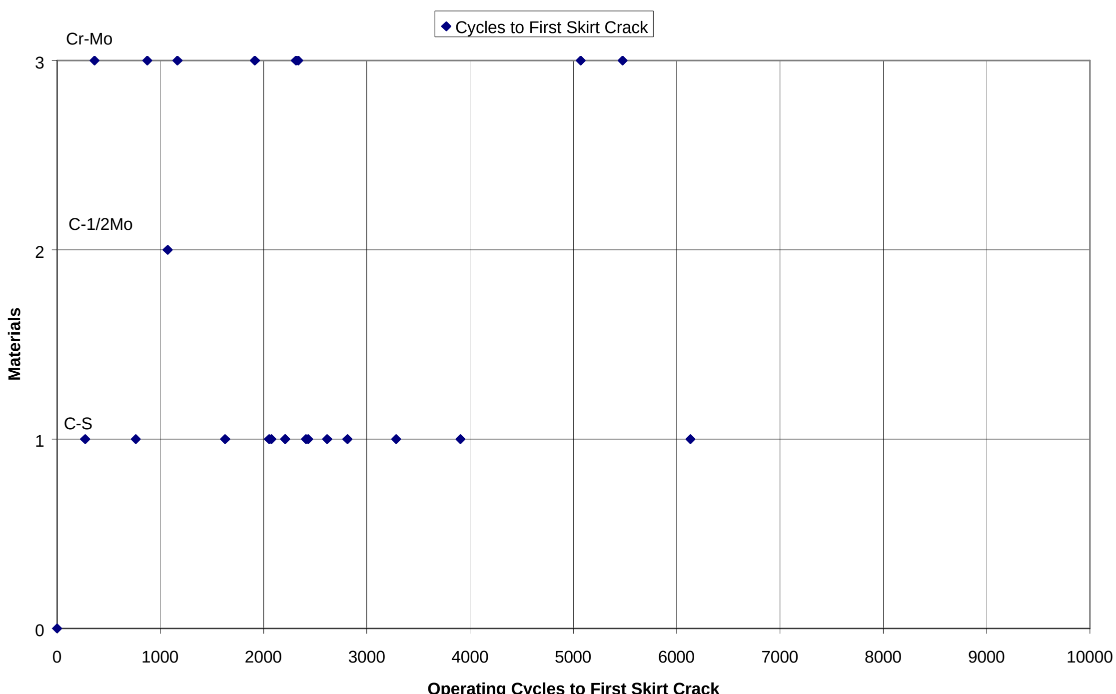

Figure 10.02

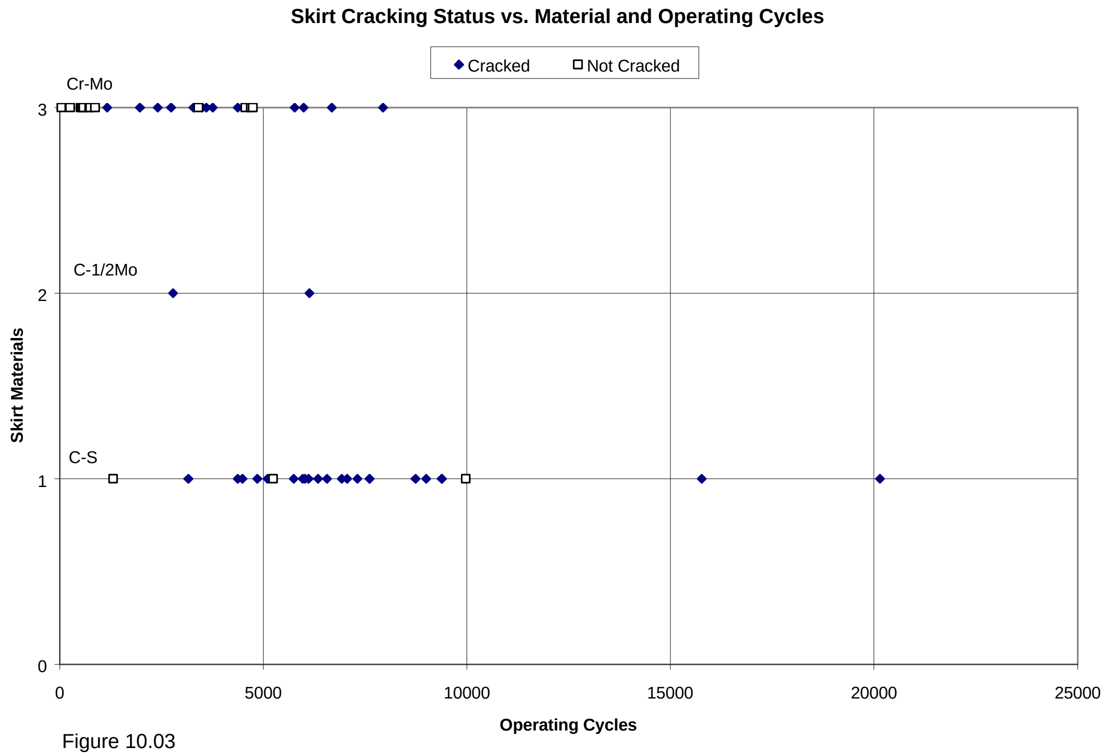

Figure 10.03

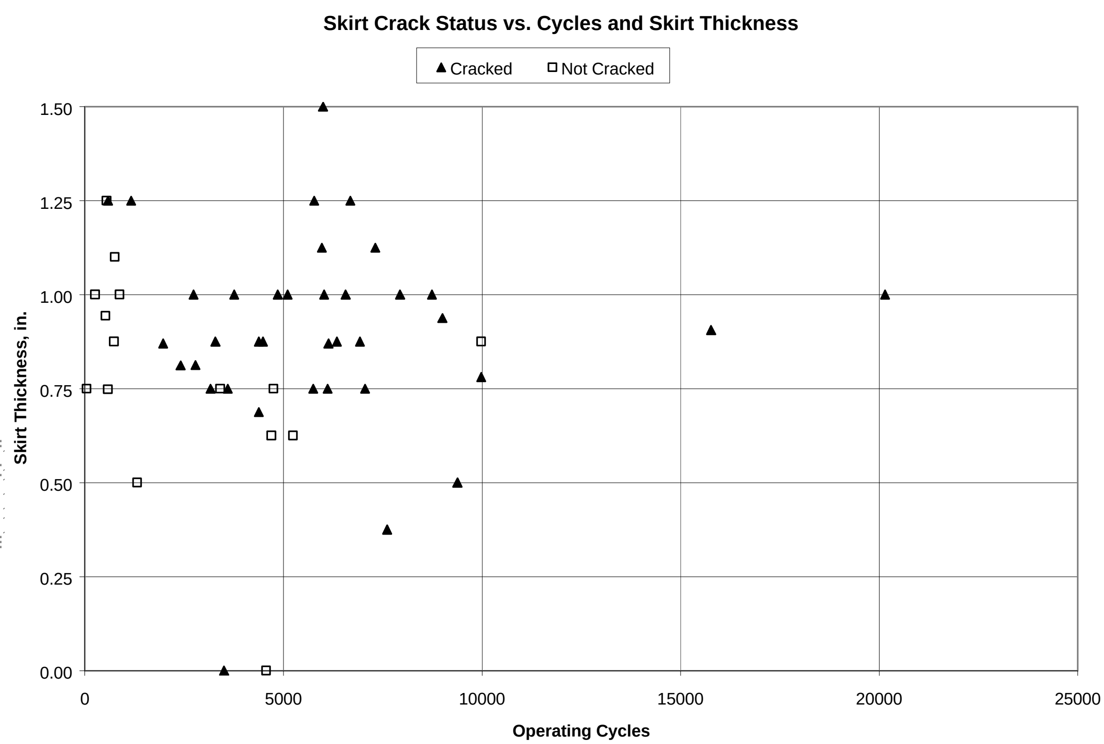

Figure 10.04

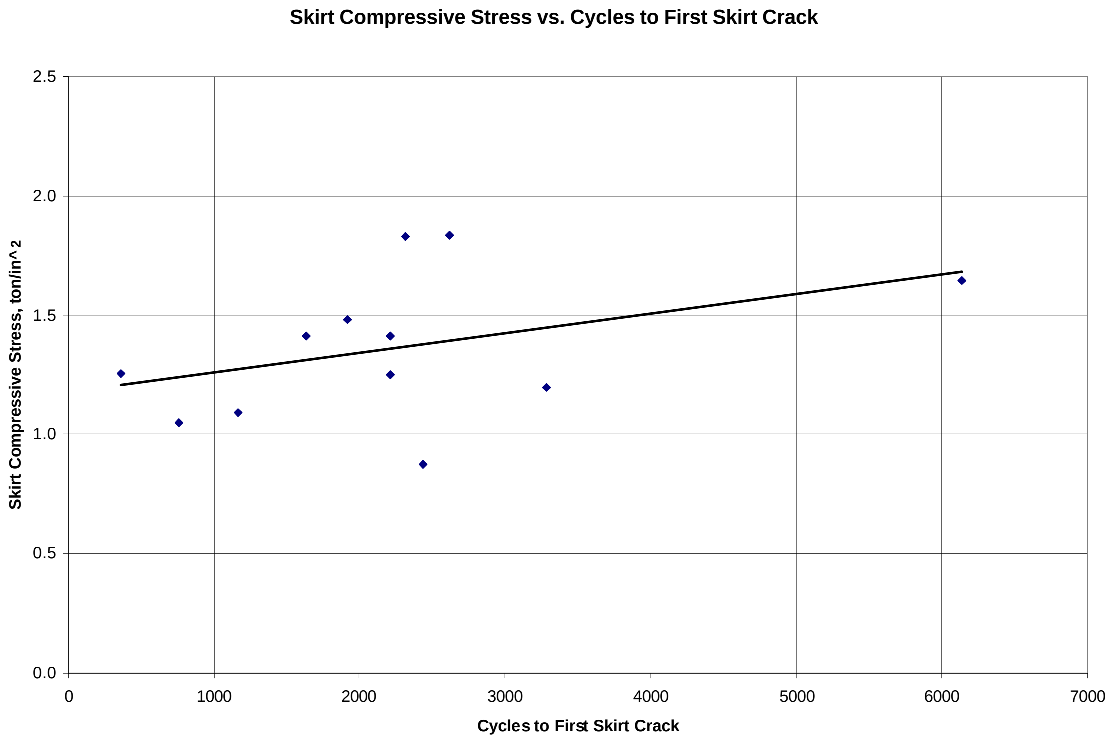
Skirt Compressive Stress vs. Cycles to First Skirt Crack
Skirt Compressive Stress, ton/in^2
2.5
2.0
1.5
1.0
0.5
0.0
0
1000
2000
3000
4000
5000
6000
7000
Cycles to First Skirt Crack

Figure 10.05

11.0 Operating Parameters Versus Cracking Experience

A number of operating parameters were evaluated and compared to the number of cracks and cycle time to the first through wall crack in order to determine if there are correlation's between operation and cracking experience. The first parameter examined was initial quench rate. Figure 11.01a plots initial quench rate in gallons per minute versus number of cracks. The trend line for this correlation indicated a fit of R^2= 0.62. **Lower initial quench rates had a significantly higher number of cycles until the first through wall crack. This correlation had the best fit of any of the parameters studied.**

When examining initial quench rate divided by diameter versus the number of cycles to first through wall crack, there was a slightly lower fit indicated by an R^2= 0.61. A larger drop in fit was observed when trying to correlate to initial quench flux (quench rate divided by drum area). Figure 11.01c displayed an R^2= 0.55.

Comparing similar parameters to the number of cracks did not produce similar results as shown in Figures 11.02 through 11.05.

Figure 11.06 shows the second parameter that indicated to have a correlation to observed damage. This figure shows the total number of cracks versus total number of cycles as a trend of drums with proofing compared to drums without proofing. The trend lines give an indication that the relationship for an increasing number of cracks is not necessarily linear but accelerates with increasing number of cycles, which agrees with general operating experience.

The proofing parameter was a difficult parameter to determine in terms of actual operation history. The greatest confidence was in the responses that indicated the use of a proof procedure. This is also the trend line with the better fit, R^2= 0.51.

The relationship with final quench rate, furnace outlet temperature, sulfur content, and drum overhead pressure was examined. These graphs are shown in Figures 11.07 though 11.14. None of these graphs showed a strong trend as compared to cycles to first through wall crack.

Figure 11.15 shows the correlation of current fill time versus cycles to first through wall crack. The curve points downward (longer life for shorter cycles), however, the poor curve fit (R^2= 0.08) indicates that there is no correlation. Similar lack of correlation was seen in comparing duration of steam stripping versus cycles to first through wall crack shown in Figure 11.16. Comparing the preheat duration versus cycles to the first skirt crack, shown in Figure 11.17, indicated that there was not a discernible correlation for this parameter.

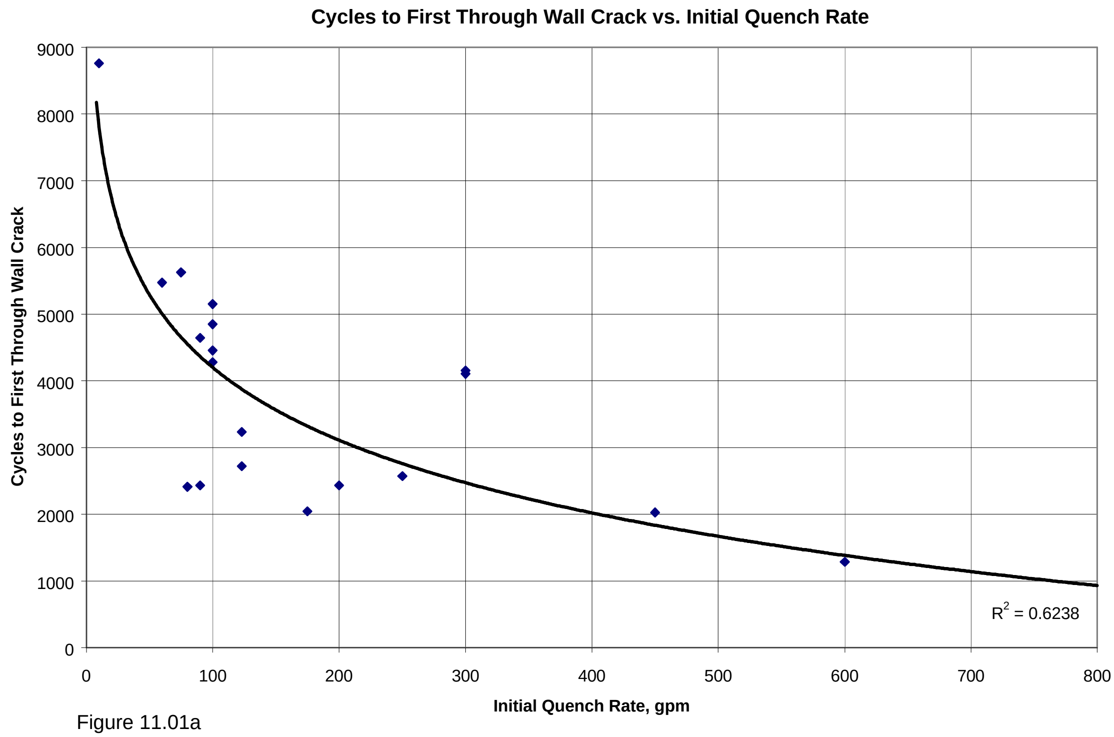

Figure 11.01a

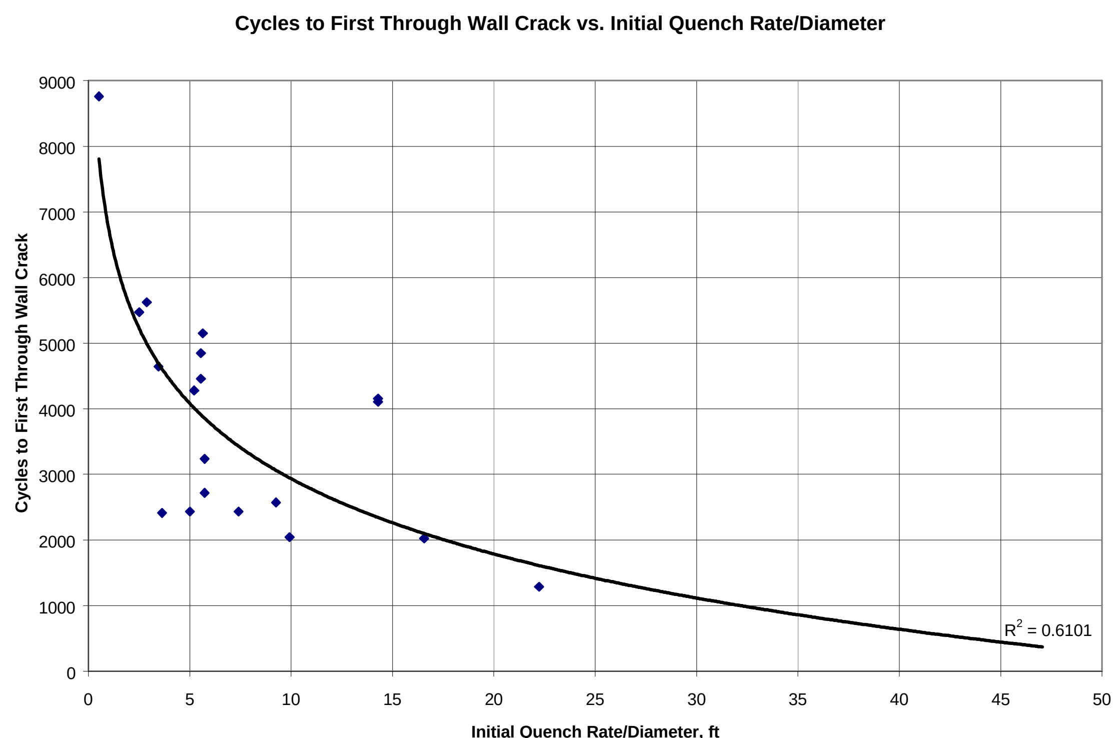

Figure 11.01b

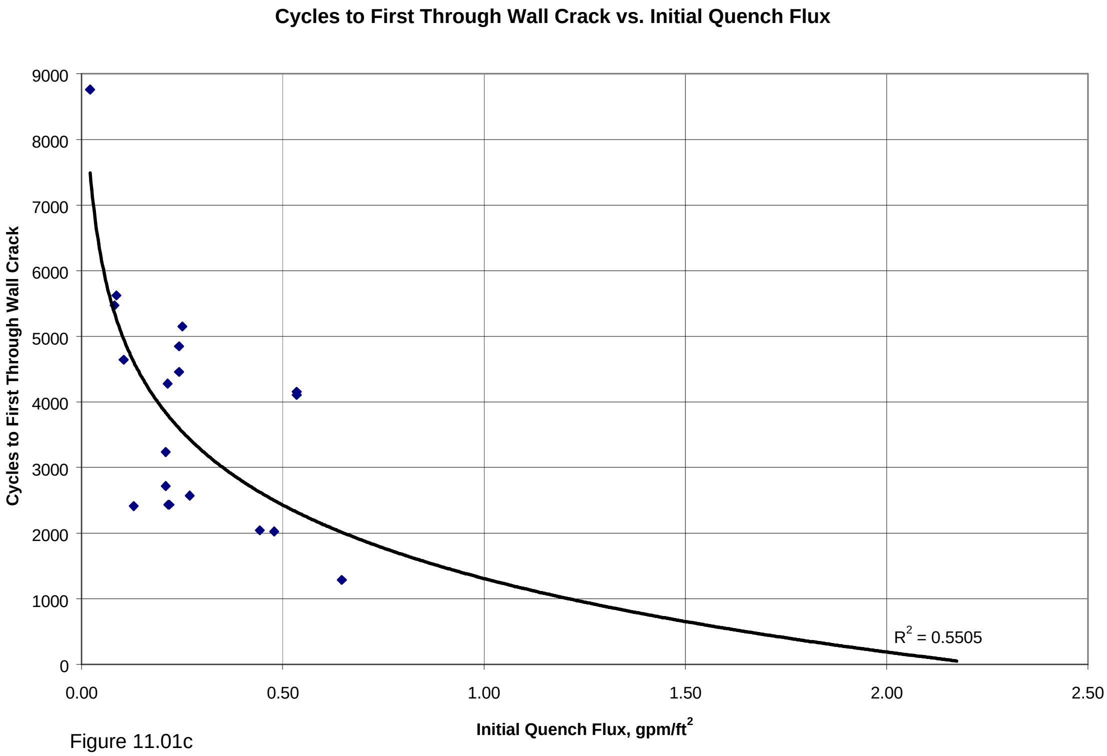

Figure 11.01c

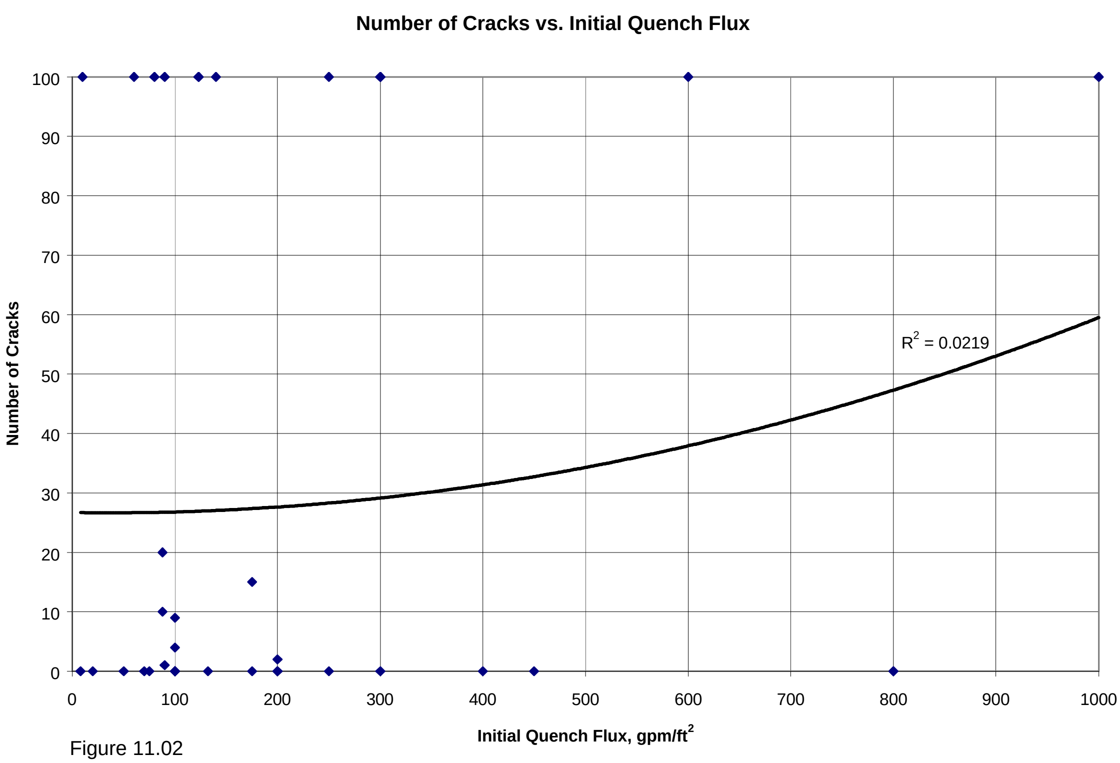

Figure 11.02

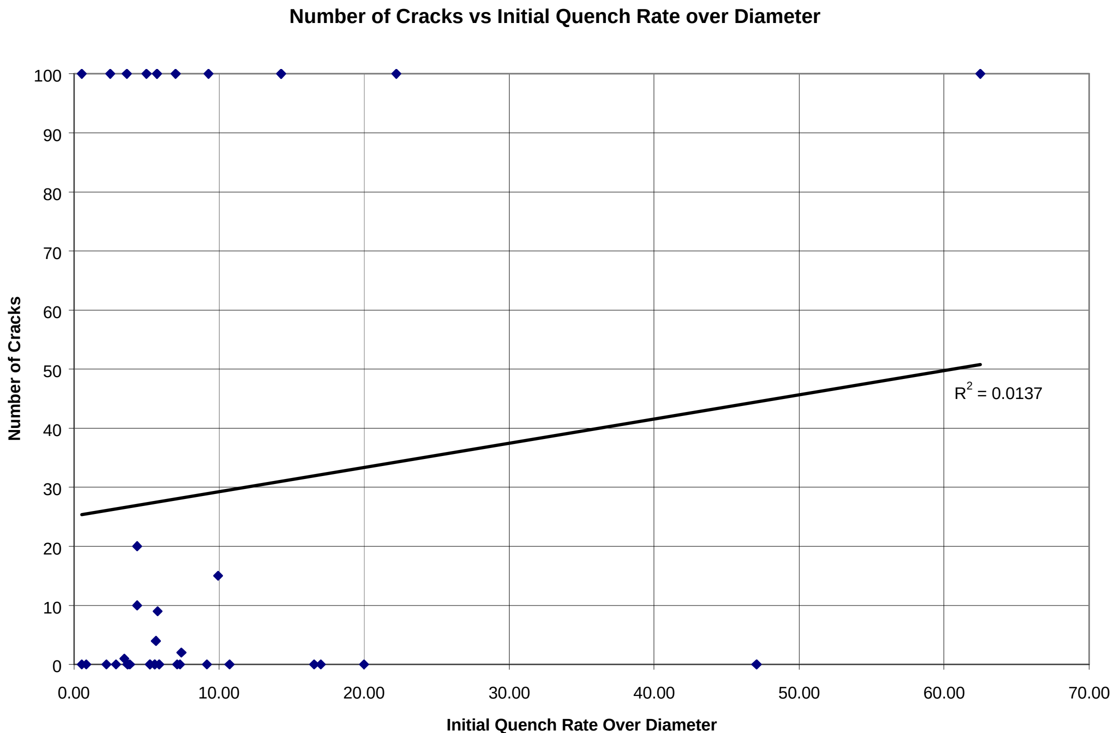

Figure 11.03

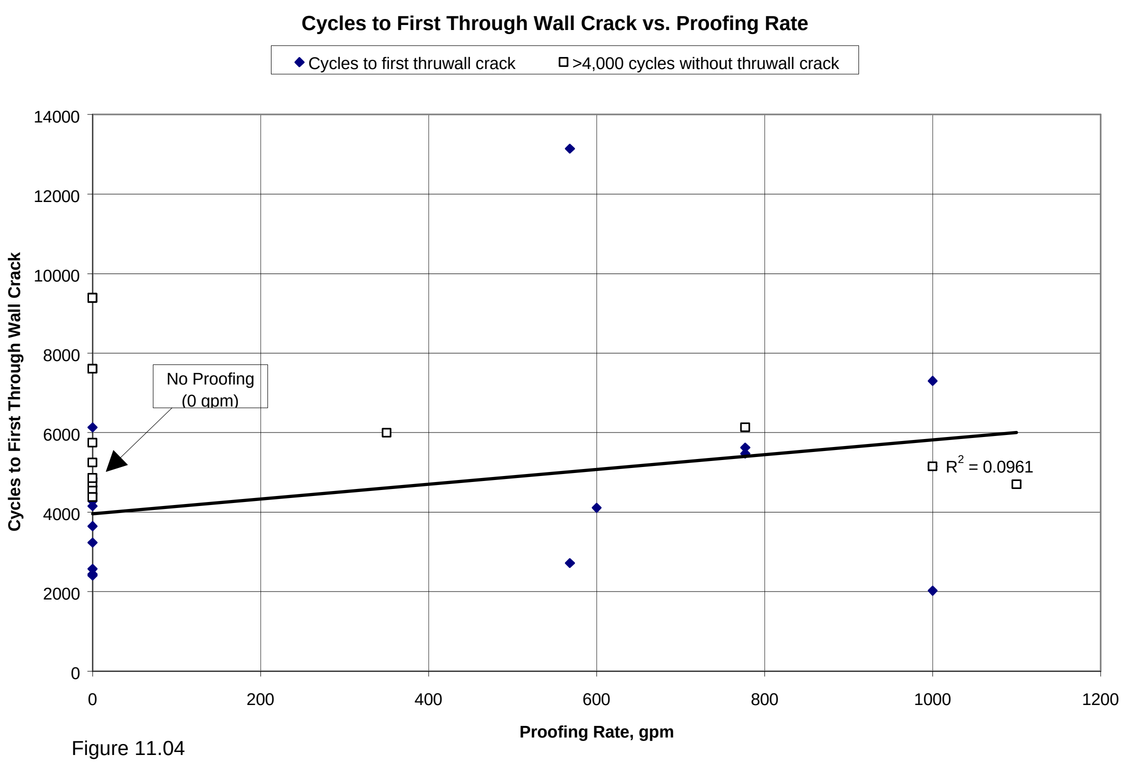

Figure 11.04

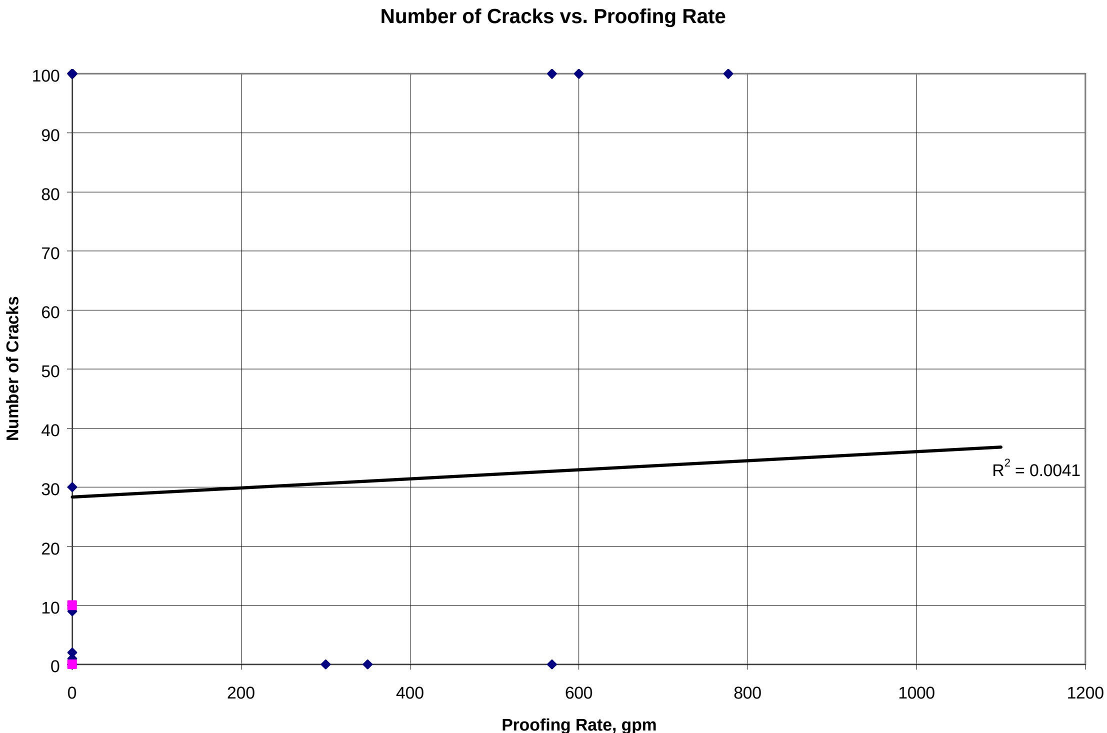

Figure 11.05

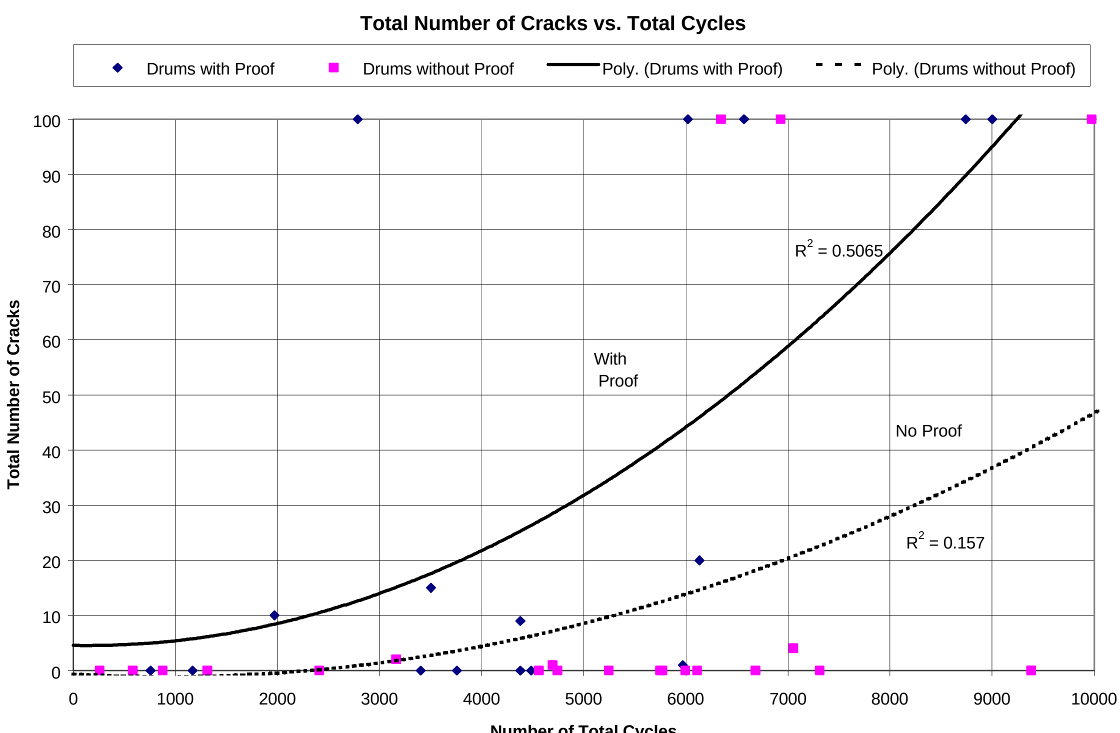

Figure 11.06

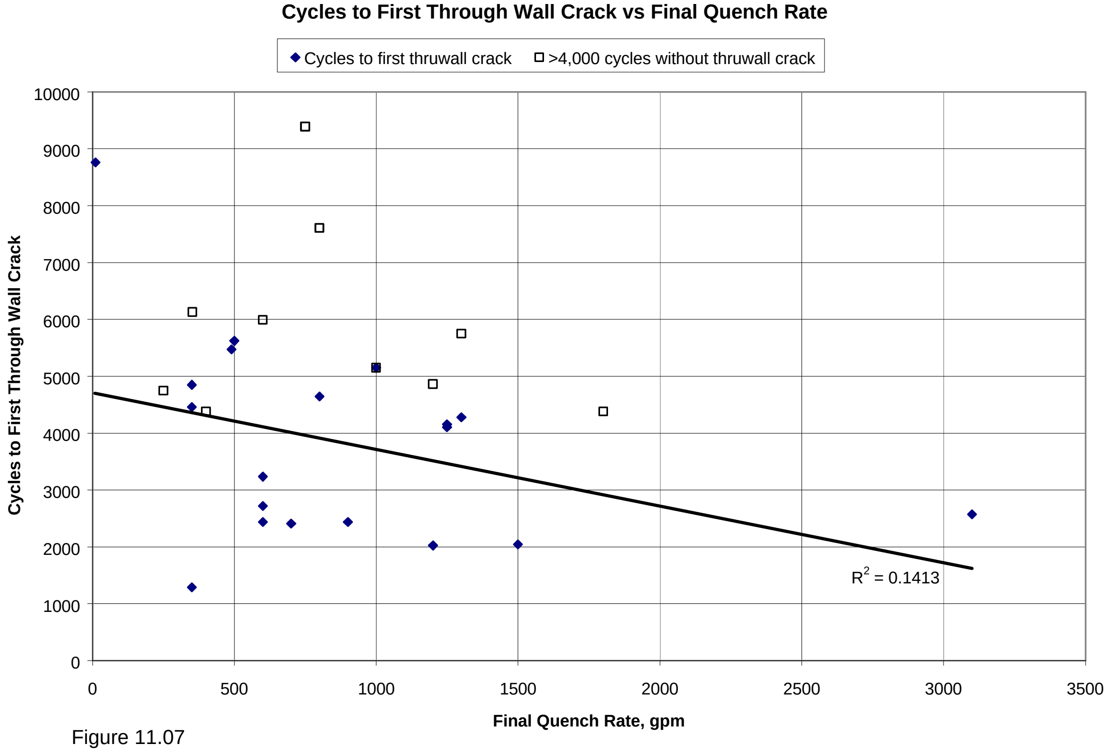

Figure 11.07

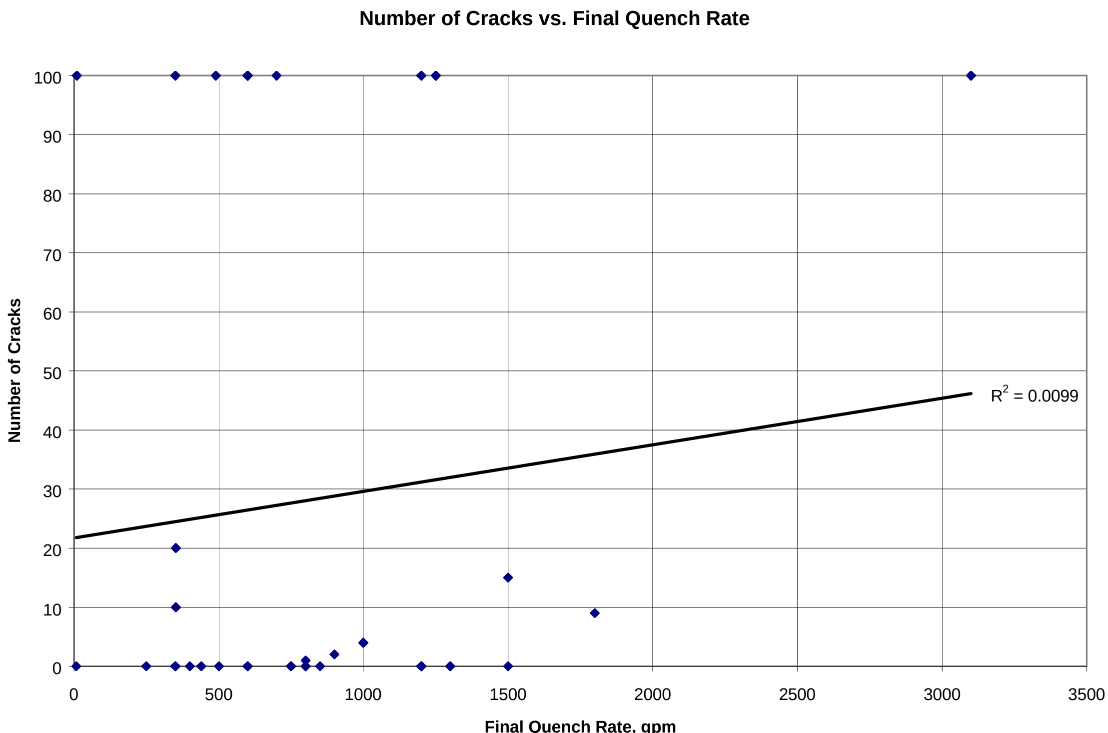

Figure 11.08

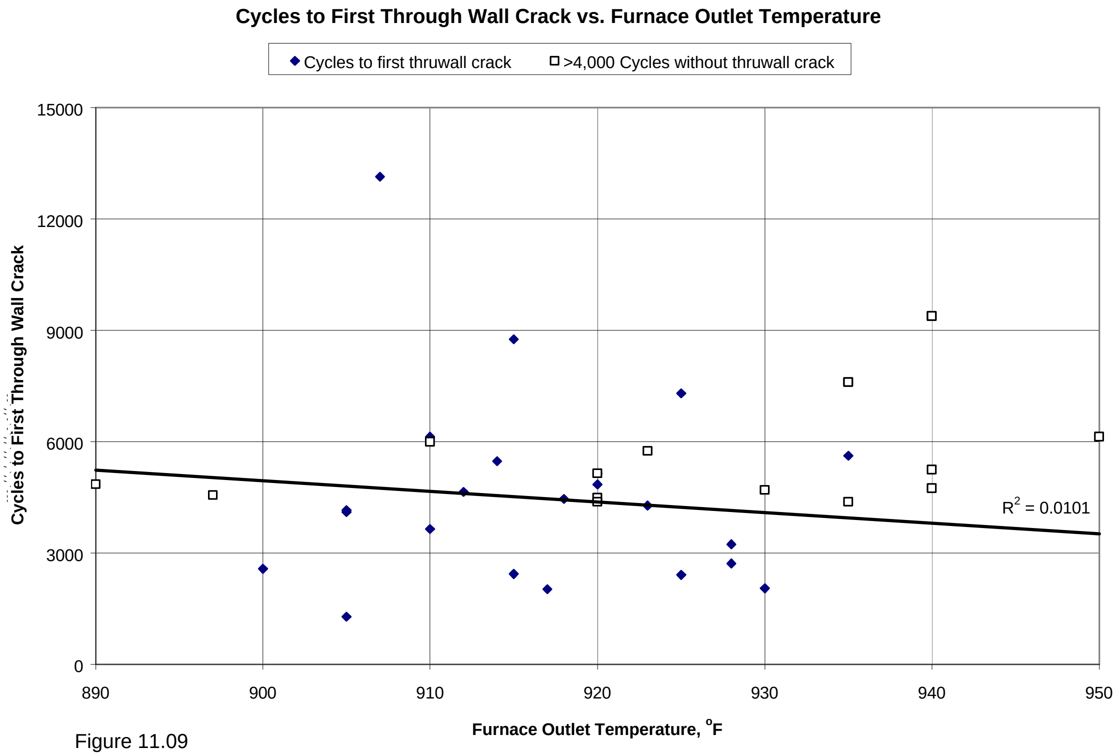

Figure 11.09

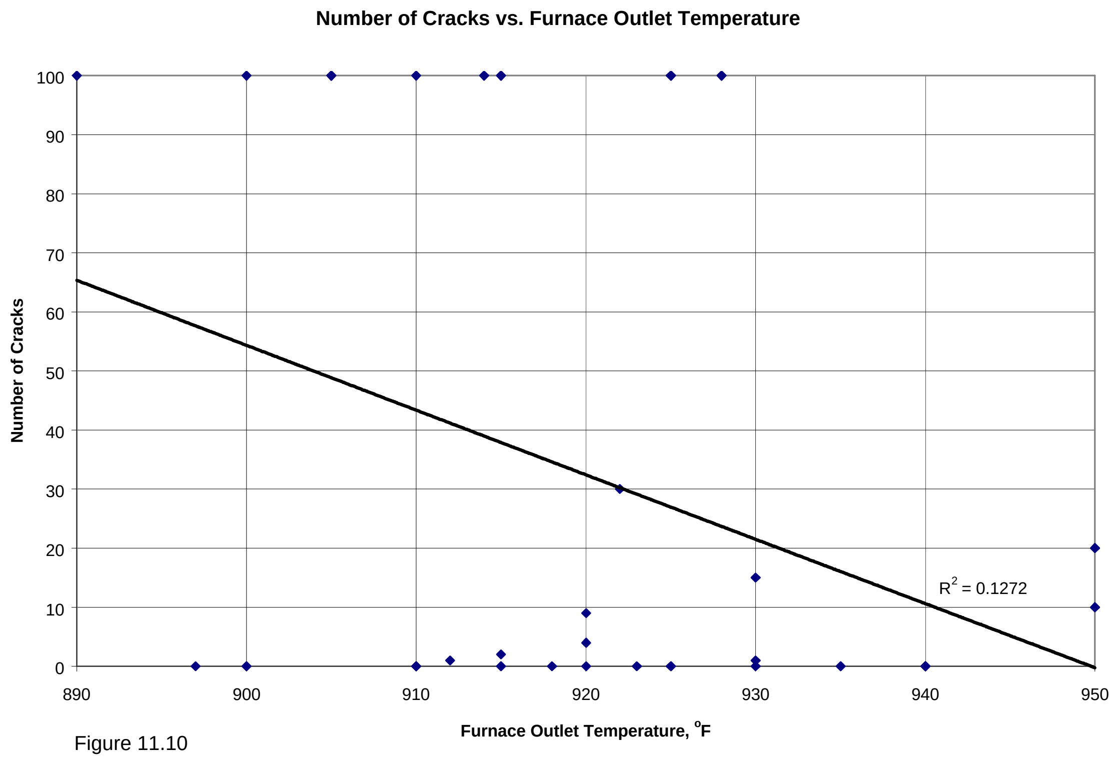

Figure 11.10

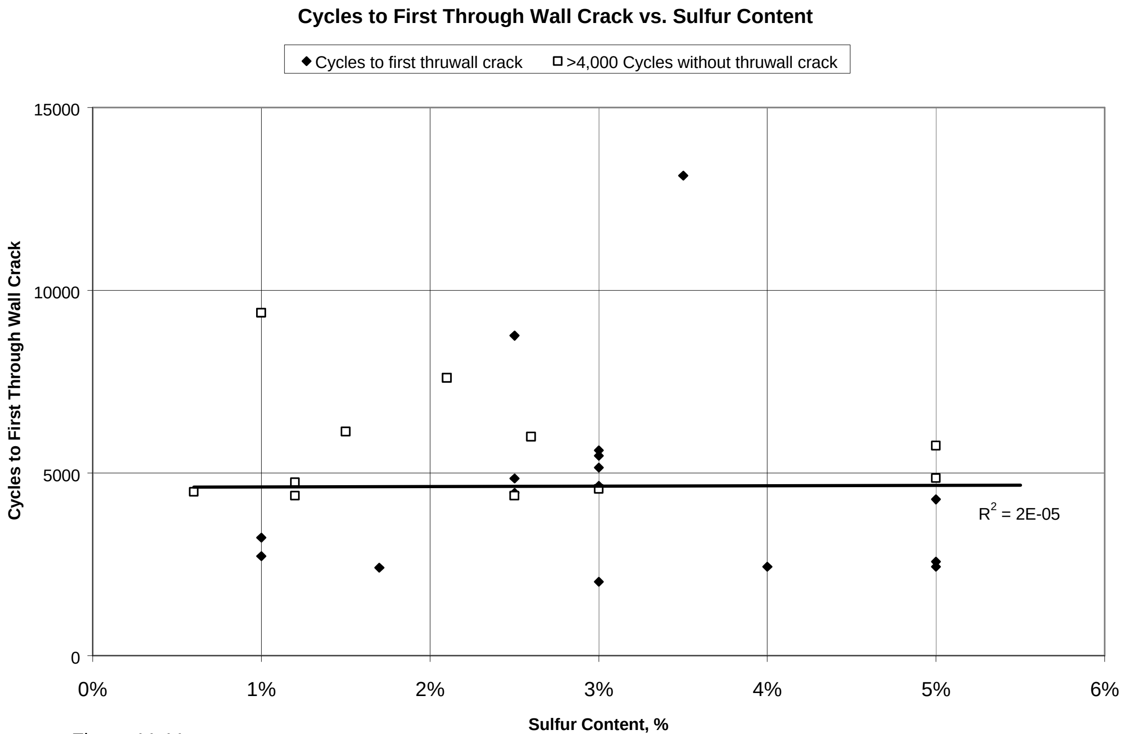

Figure 11.11

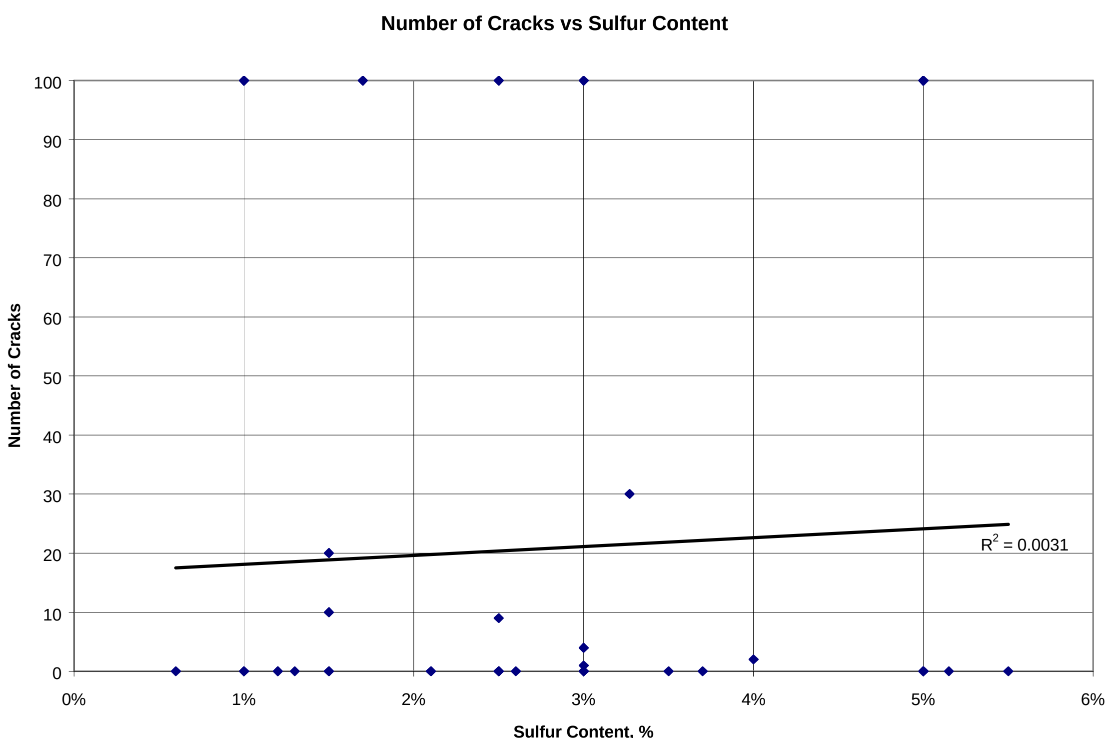

Figure 11.12

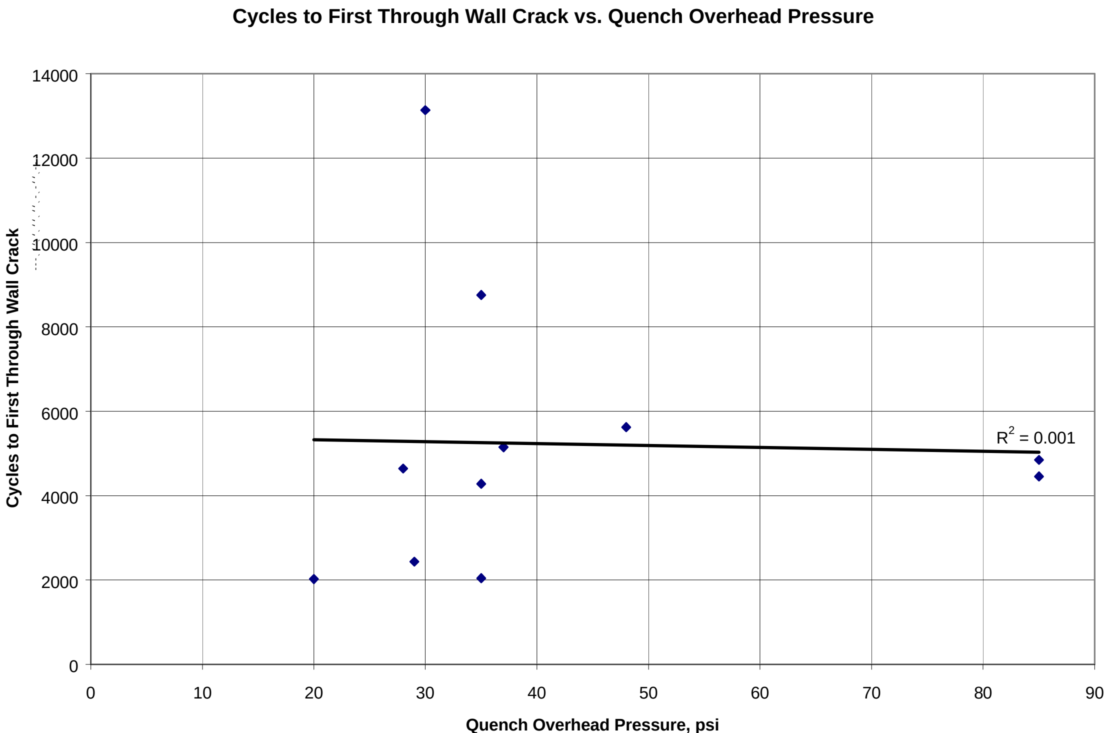

Figure 11.13

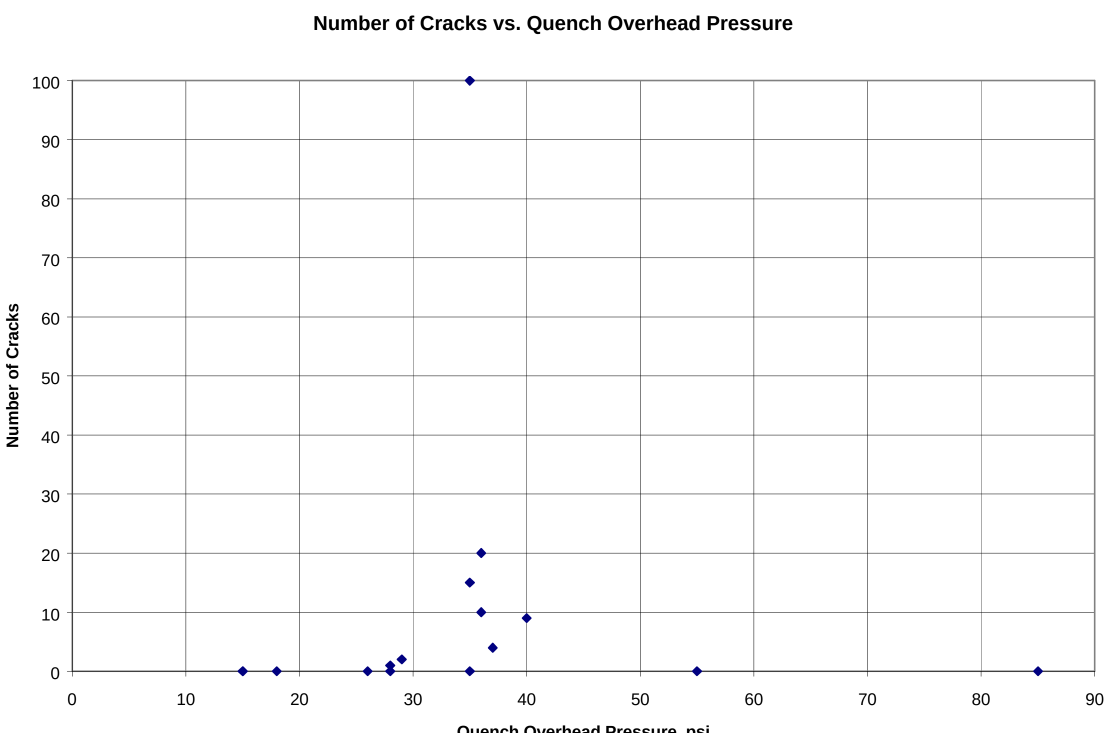

Figure 11.14

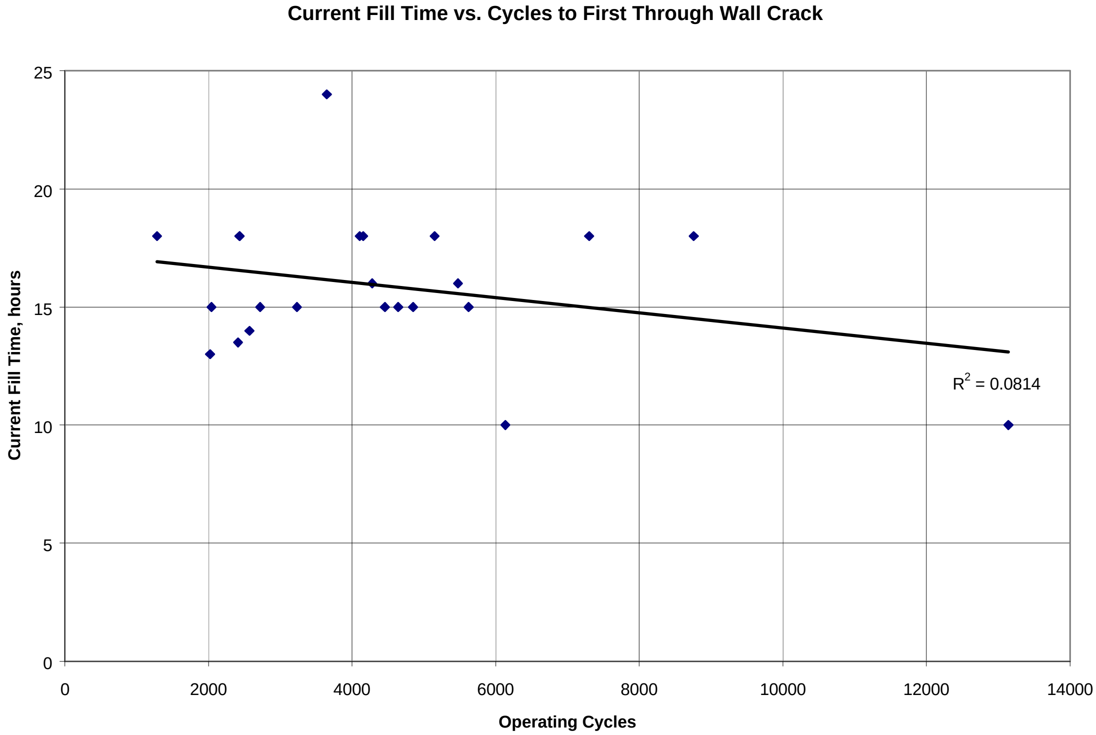

Figure 11.15

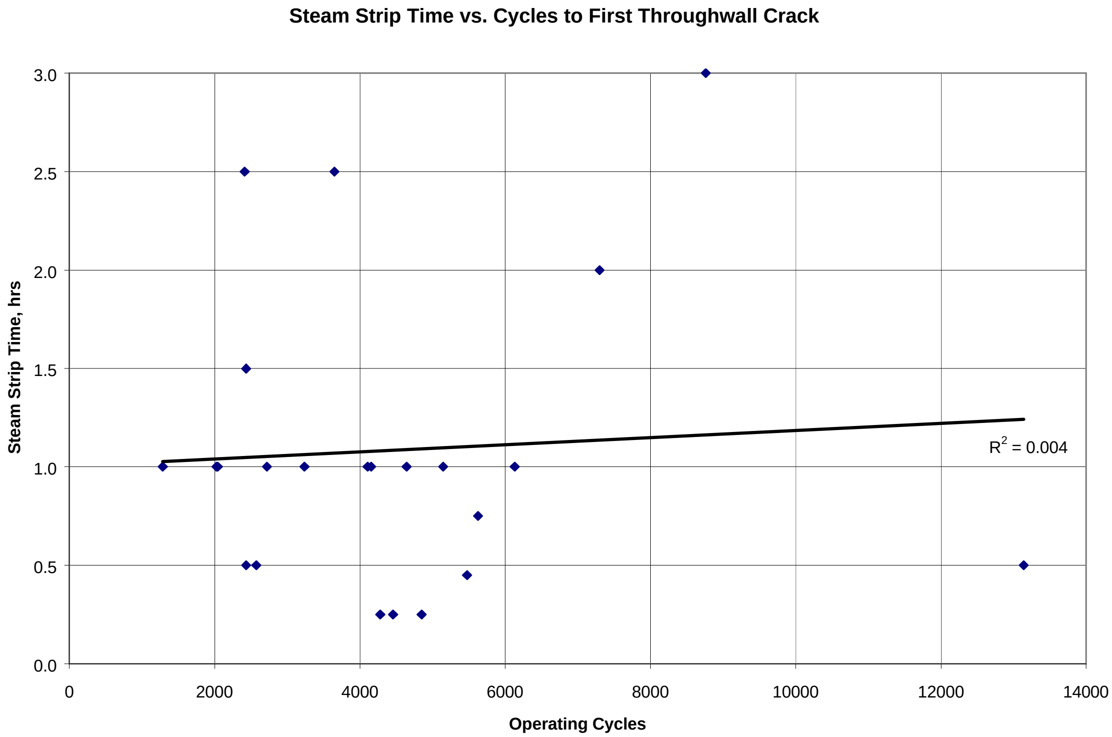

Figure 11.16

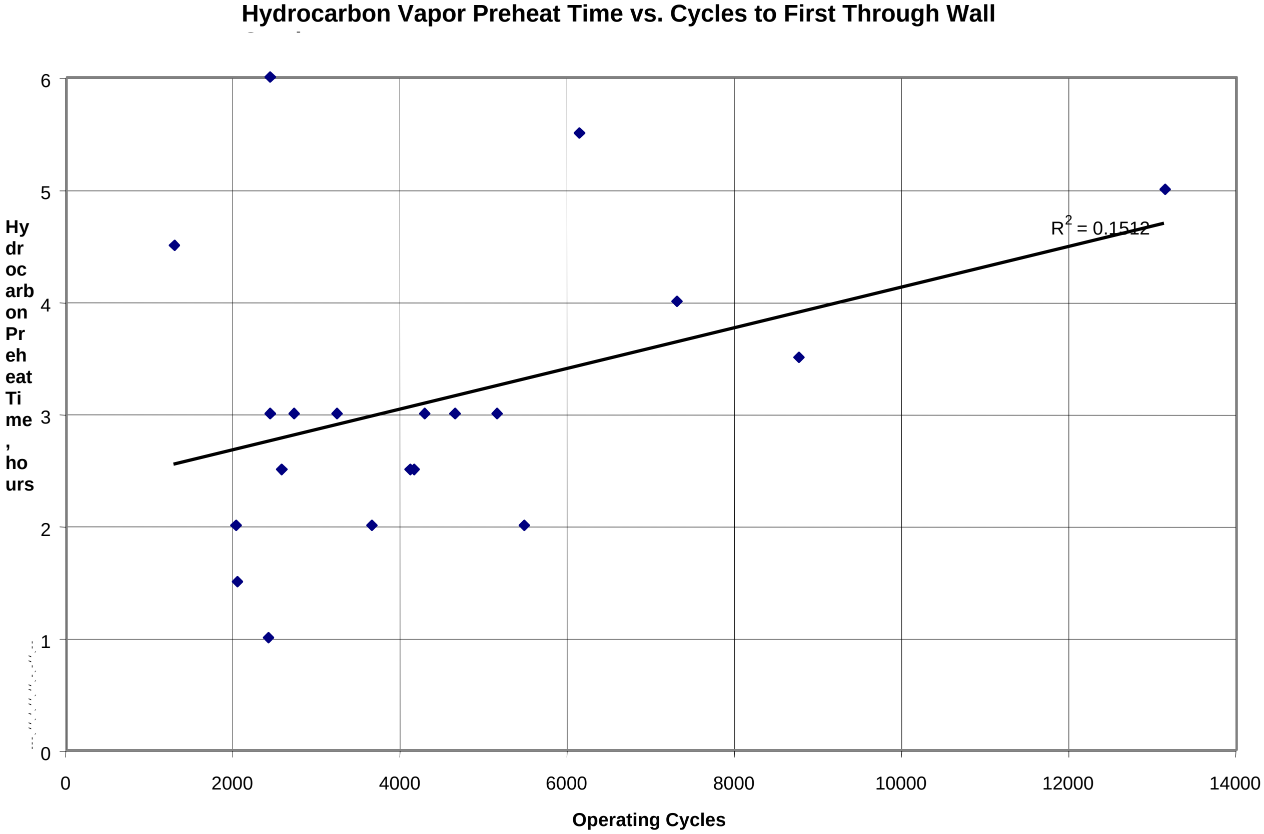
Hydrocarbon Vapor Preheat Time vs. Cycles to First Through Wall
Hydrocarbon Preheat Time, hours
0
1
2
3
4
5
6
0
2000
4000
6000
8000
10000
12000
14000
Operating Cycles
R2 = 0.1512

Figure 11.17

12.0 Bulging Versus Operating Parameters

Bulging versus operating parameters was also examined. Figure 12.01 shows similar parameters as in Section 11. These graphs show that there is no correlation based on the low fit indicator R^2= 0.02. Graphs shown in Figures 12.02 through 12.04 compare the number of bulges with the initial quench parameters. These graphs displayed an even lower correlation factor R^2= 0.01.

Figure 12.05 shows an interesting trend. Drums with proofing displayed a better fit and coincided with the results shown in the trends for number of cracks for drums that employ proofing techniques.

Final quench is shown in Figures 12.06 and 12.07 for the cycles to first bulge and number of bulges.

Furnace outlet temperature had considerable scatter and opposite trend lines when comparing cycles to first bulge and number of bulges versus the furnace outlet temperature as shown in Figures 12.08 and 12.09.

It is indicated that there is a low accuracy in the estimates of cycles to first bulge. This is due to the difficulty in accurately determining when a bulge actually occurred. This is contrasted with cycles to first through wall crack. Because of the nature of a leak, detection is easier.

In summary, these results indicate that proofing might have a correlation to bulging. However, no correlation was found between initial quench rate, final quench rate or furnace outlet temperature.

13.0 Future Survey Recommendations

Given the complexity of the design and operation of coke drums, it is anticipated that there would be minimal value in performing another industry wide coke drum survey in 10 years.

If a survey was performed in the future, it is recommended to selectively survey younger drums made of similar materials and experienced fewer variations in cycle time and operation.

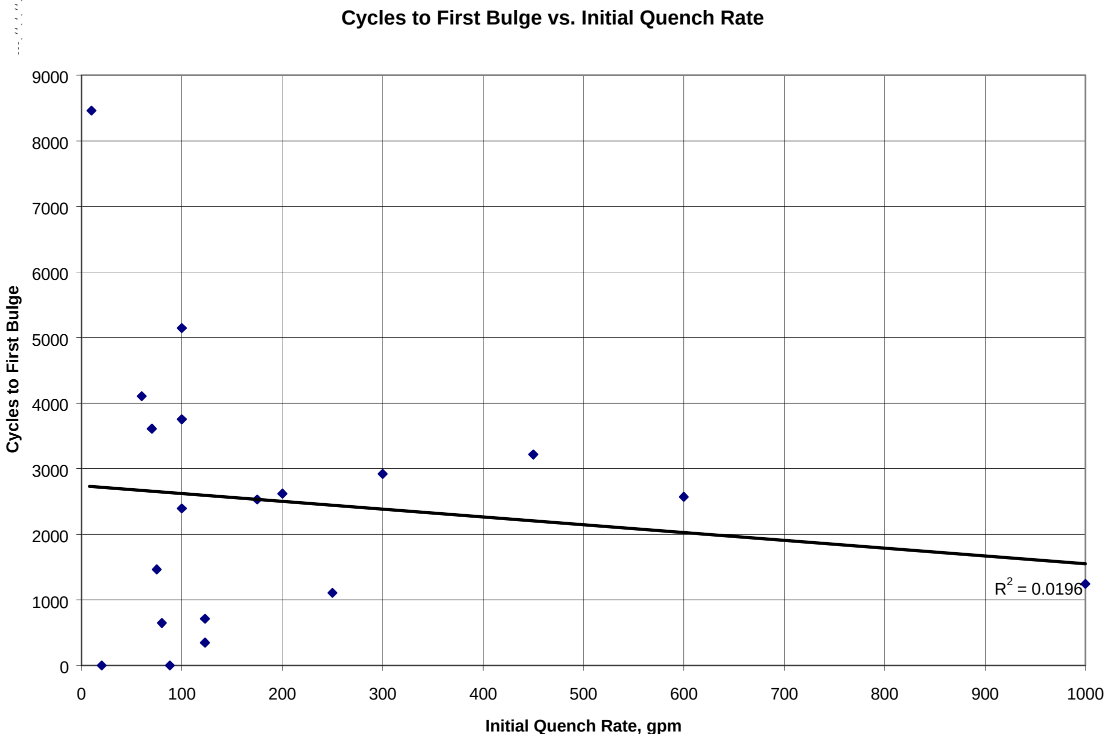

Figure 12.01a

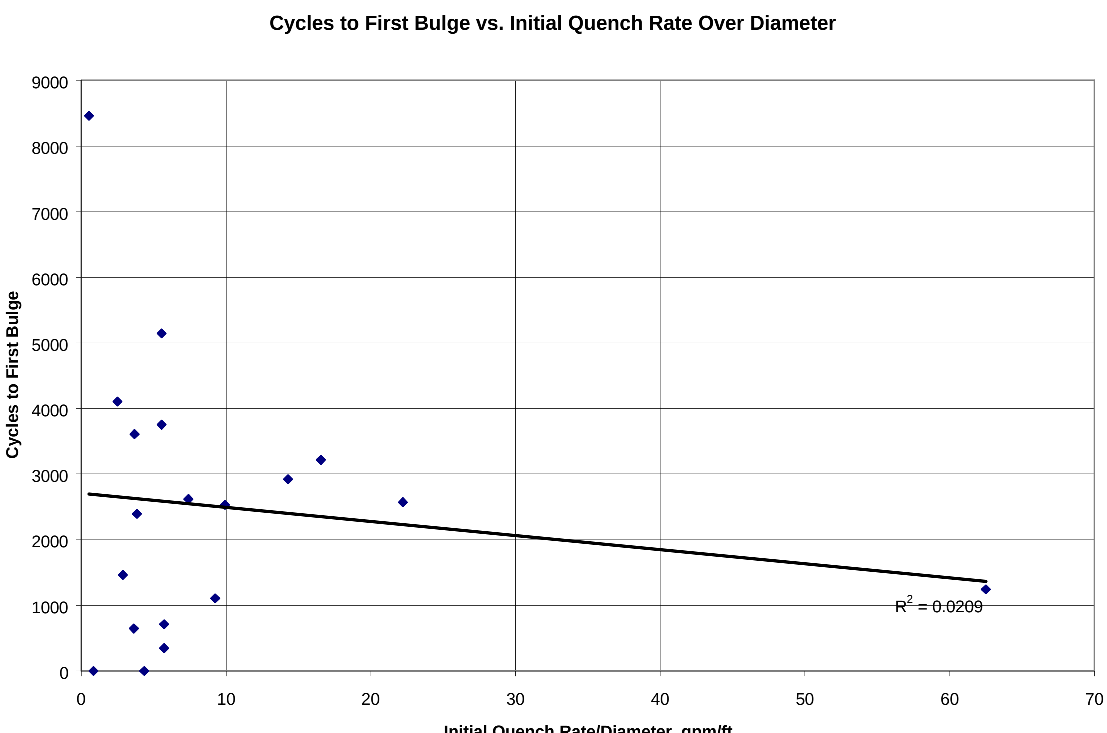

Figure 12.01b

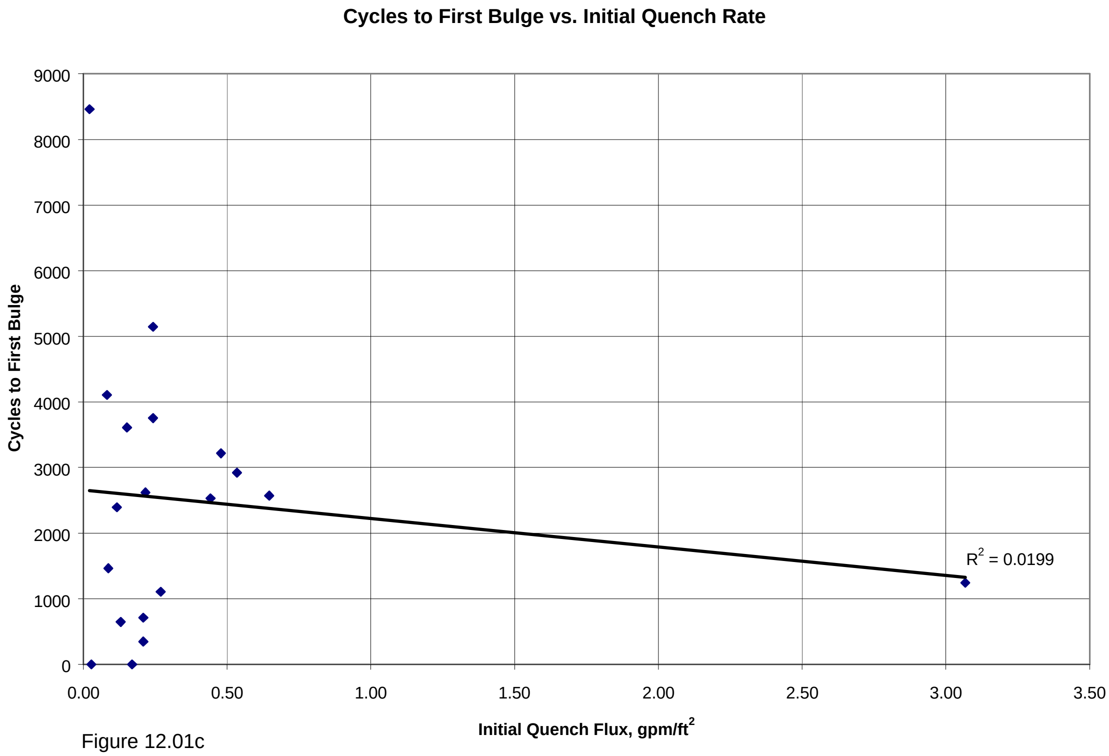

Figure 12.01c

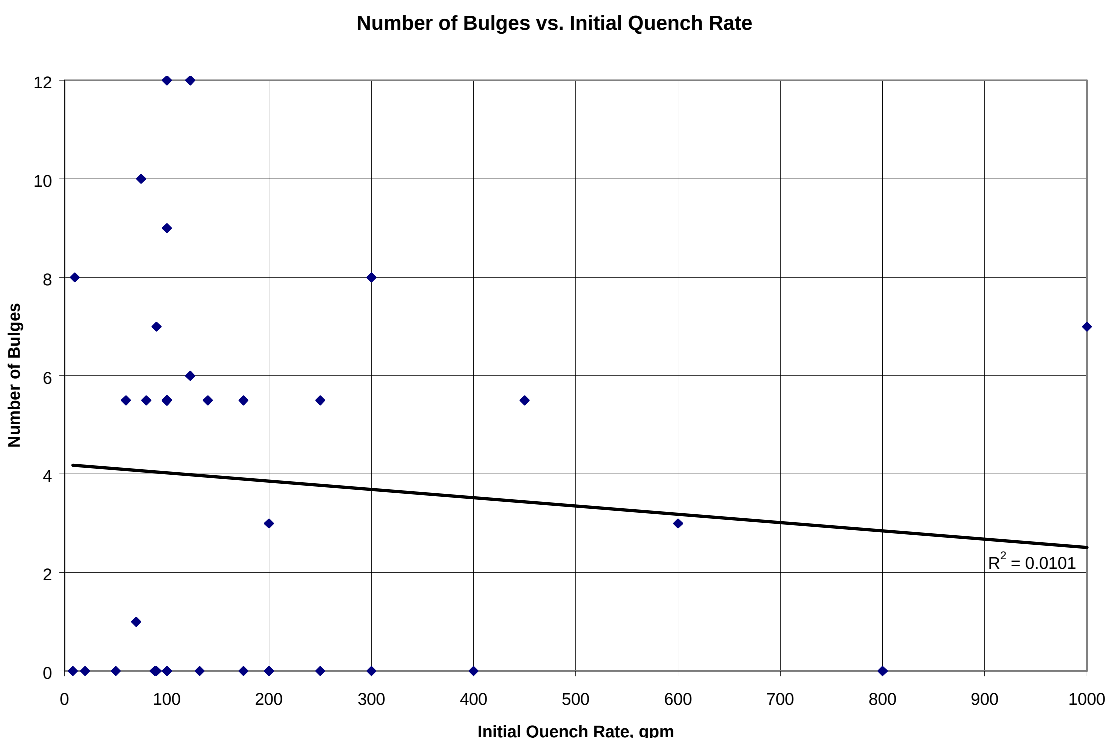

Figure 12.02a

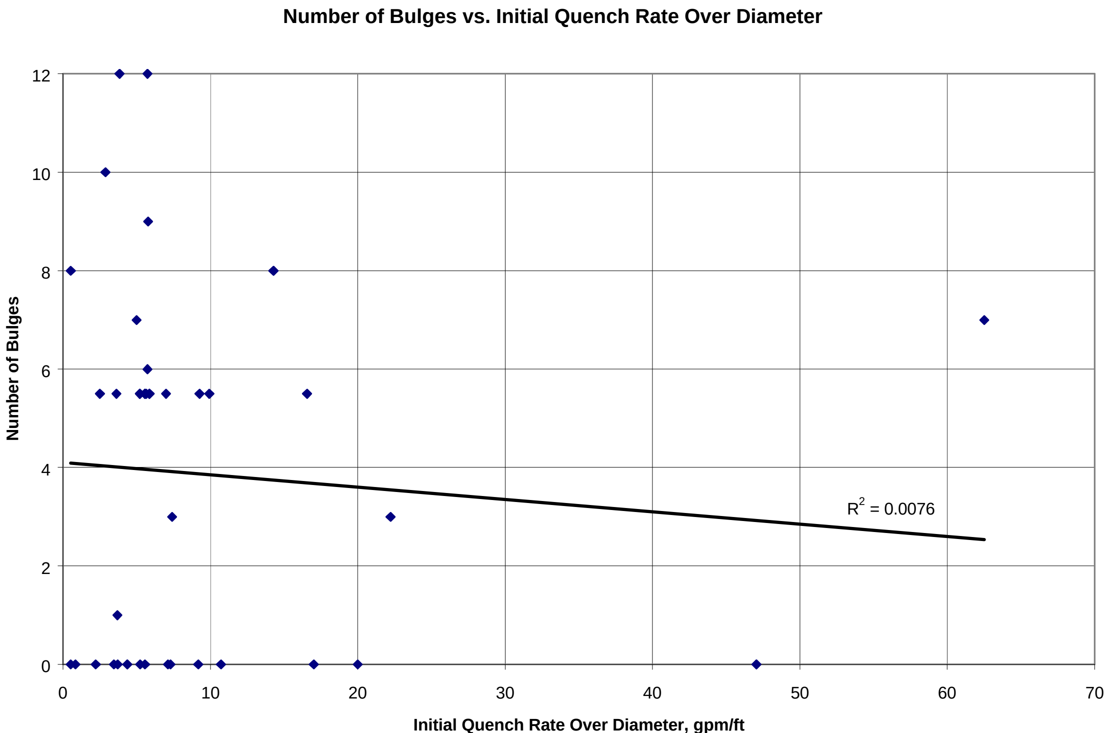

Figure 12.02b

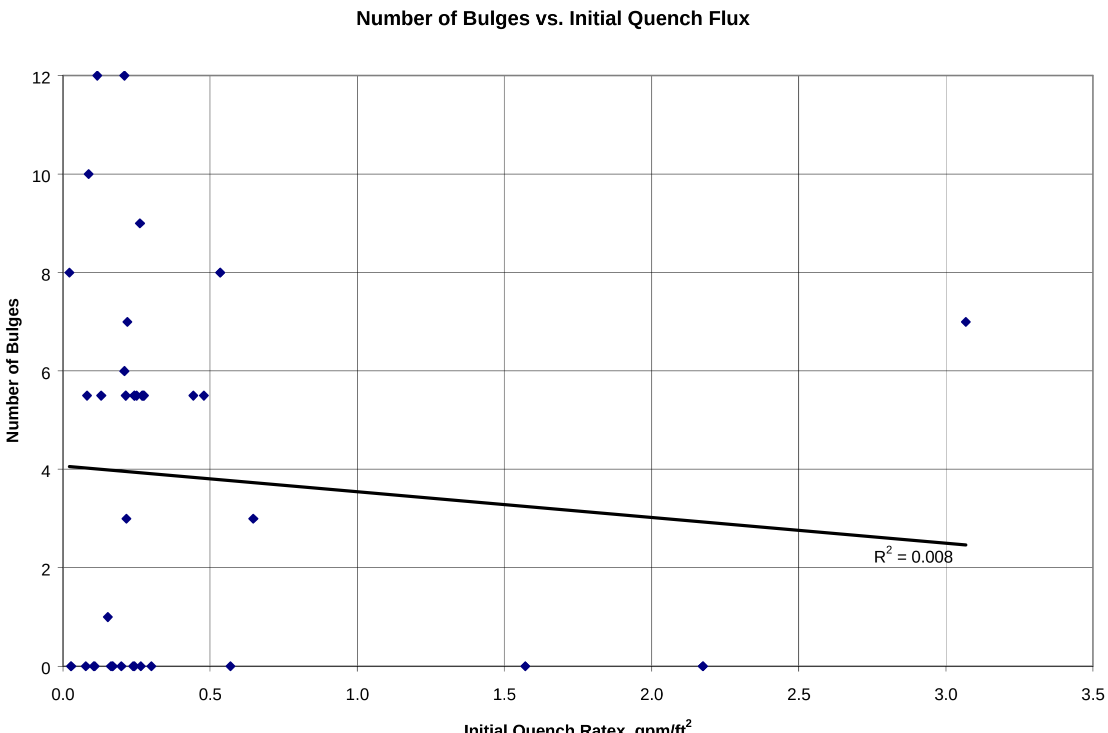

Figure 12.02c

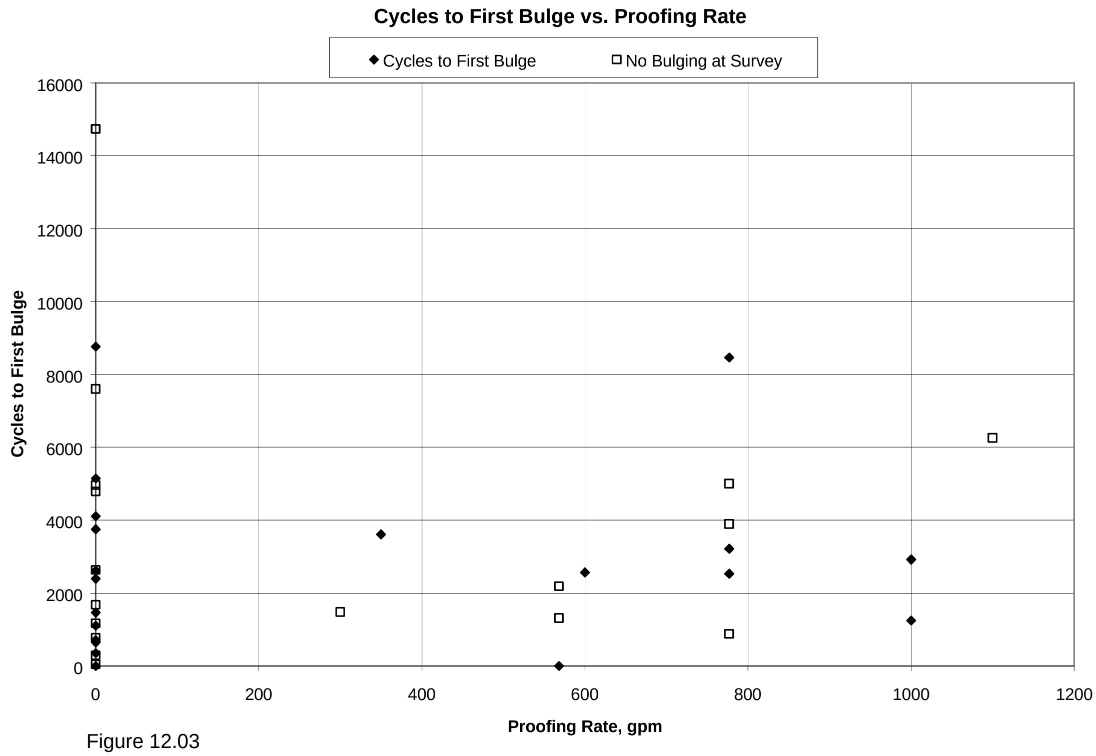

Figure 12.03

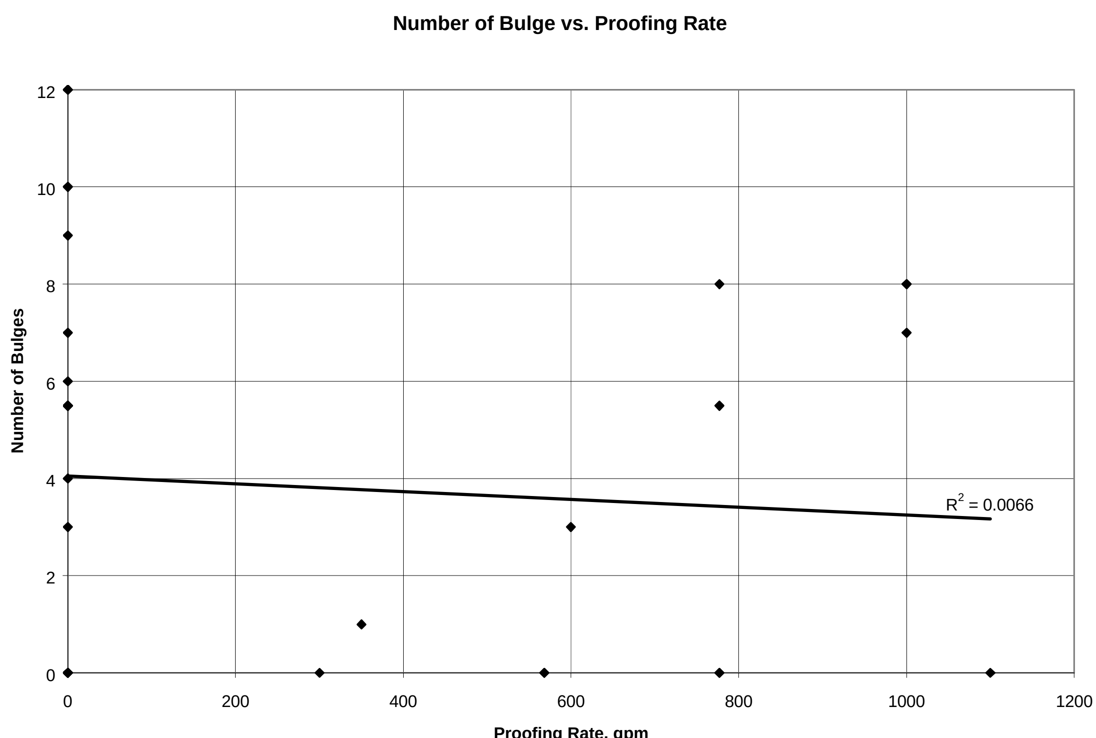

Figure 12.04

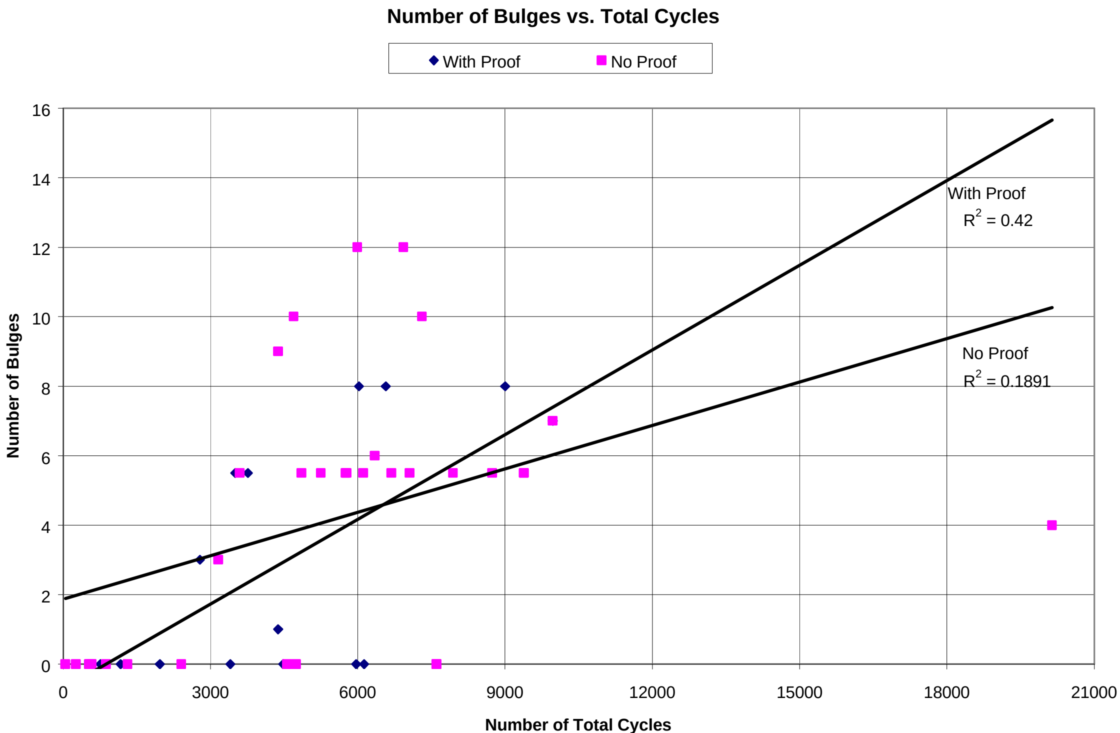

Figure 12.05

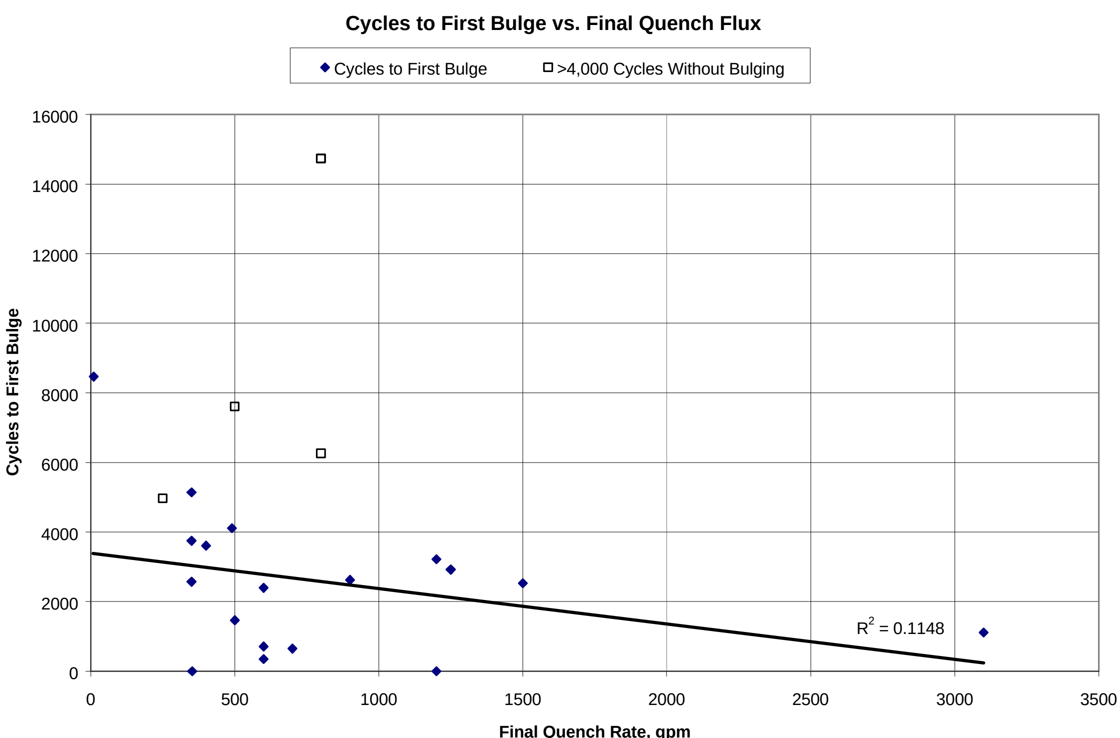

Figure 12.06a

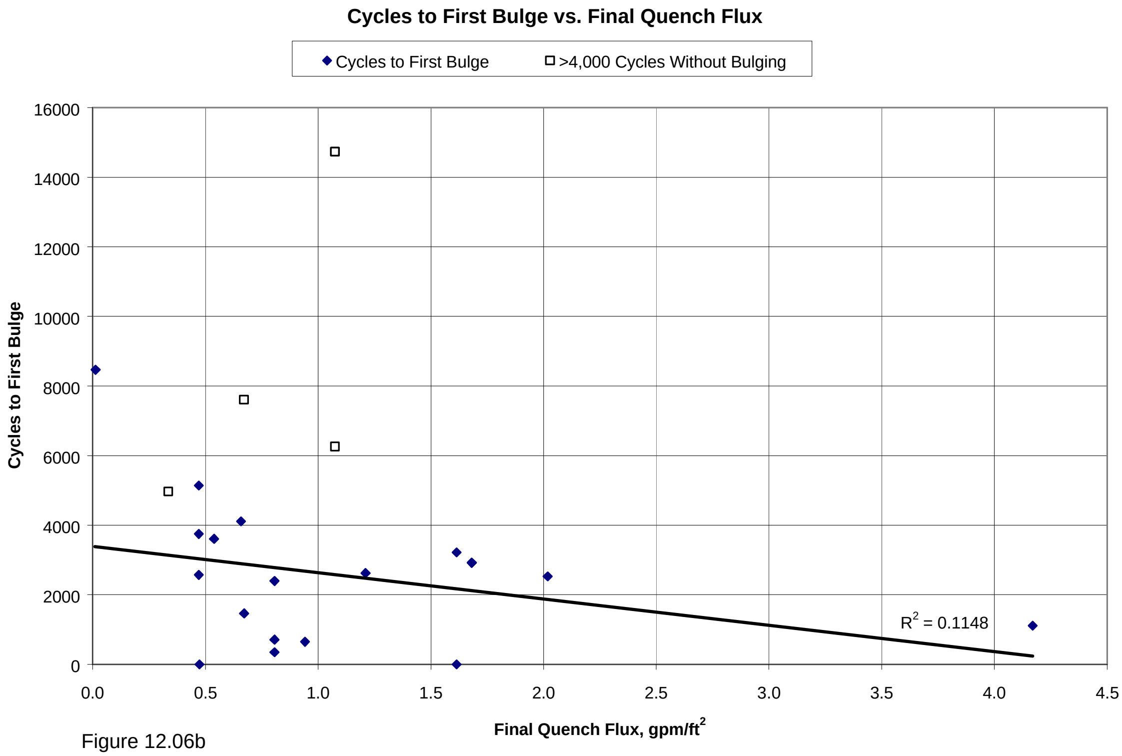

Figure 12.06b

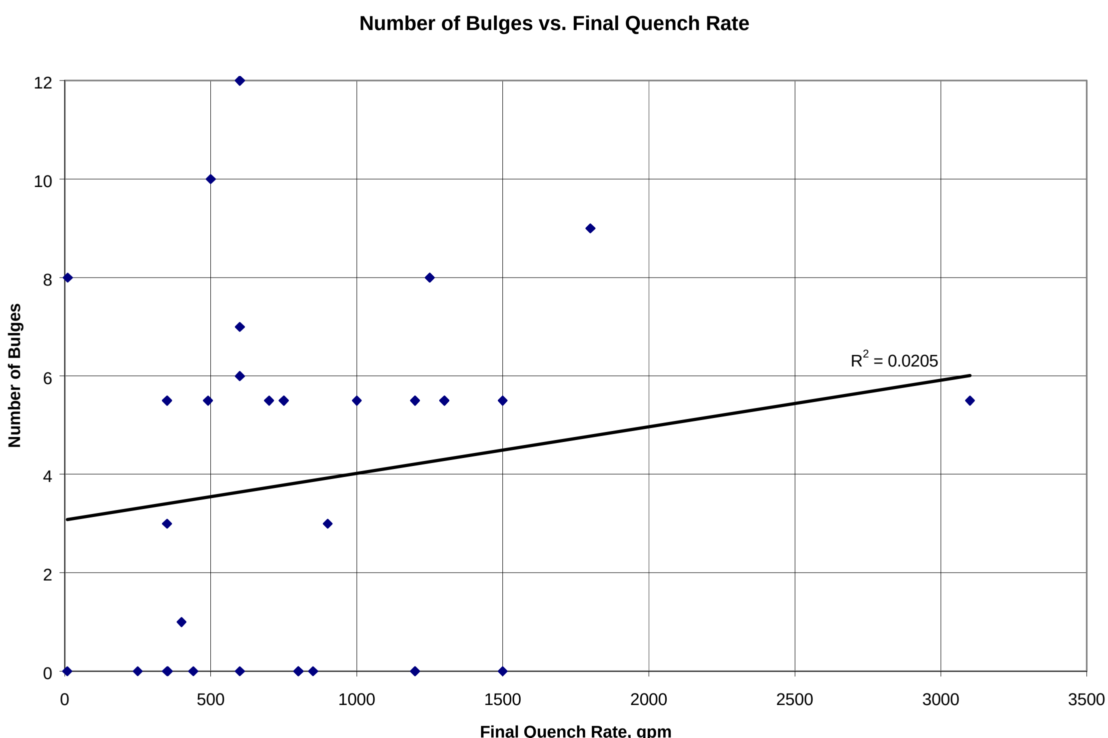

Figure 12.07a

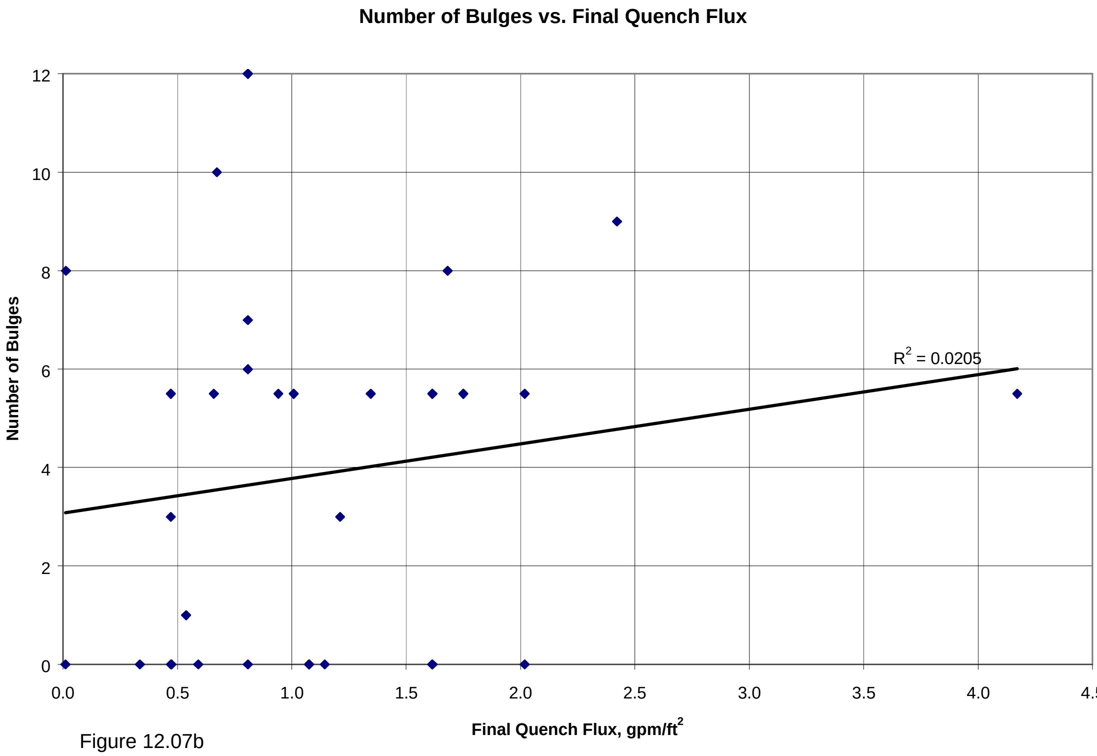

Figure 12.07b

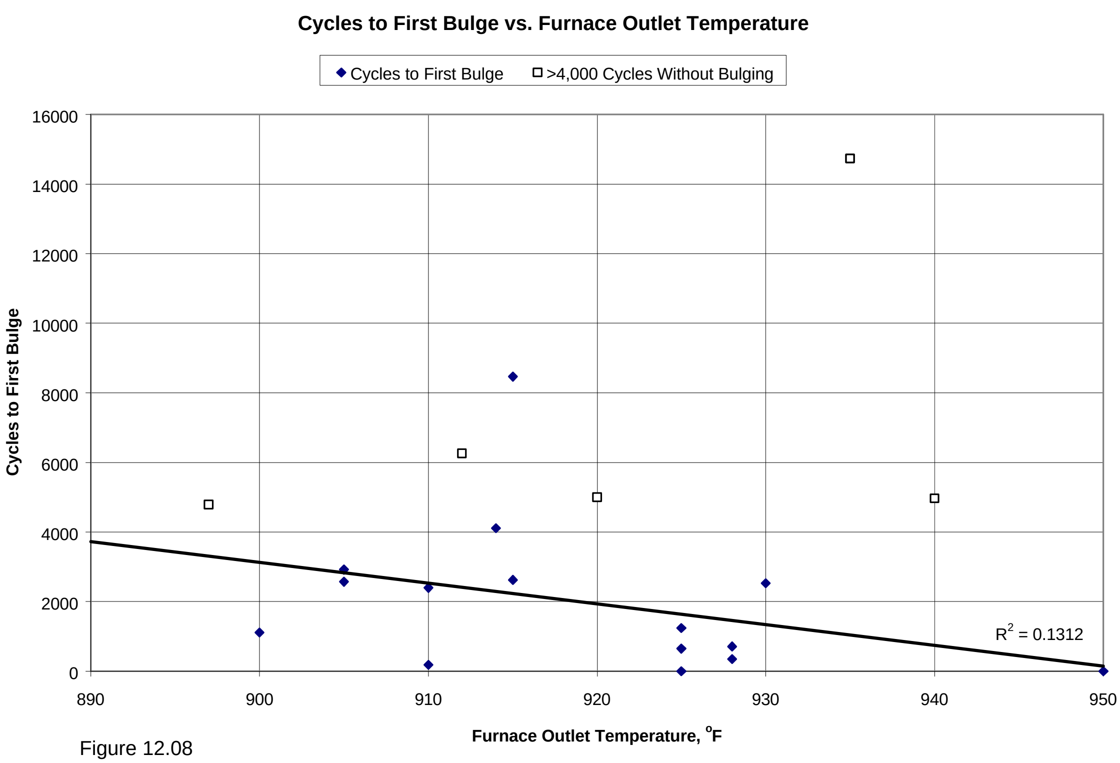

Figure 12.08

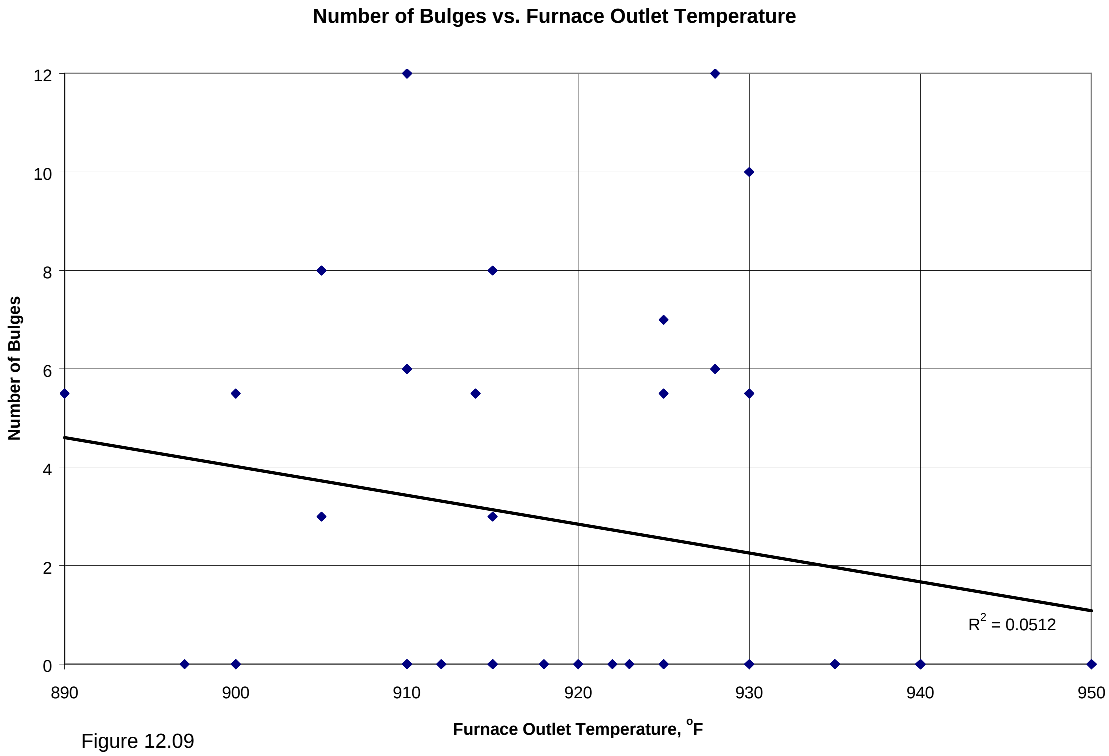
Number of Bulges vs. Furnace Outlet Temperature
Number of Bulges
12
10
8
6
4
2
0
890
900
910
920
930
940
950
Furnace Outlet Temperature, °F
R² = 0.0512

Figure 12.09

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