Reassessment of True Core Collapse Differential Pressure Values for Filter Elements in Safety Critical Environments - 13076

Adam Swain
Porvair Filtration Group, 1 Concorde Close, Segensworth,
Hampshire, PO15 5RT, England
Adam.swain@porvairfiltration.com

ABSTRACT

As the areas of application for diverse filter types increases, the mechanics and material sciences associated with the hardware and its relationship with more and more arduous process environments becomes critical to the successful and reliable operation of the filtration equipment.

Where the filter is the last safe barrier between the process and the life environment, structural integrity and reliability is paramount in both the validation and the ethical acceptability of the designed equipment.

Core collapse is a key factor influencing filter element selection, and is an extremely complex issue with a number of variables and failure mechanisms. It is becoming clear that the theory behind core collapse calculations is not always supported with real tested data. In exploring this issue we have found that the calculation method is not always reflective of the true as tested collapse value, with the calculated values being typically in excess or even an order of magnitude higher than the tested values. The above claim is supported by a case study performed by the author, which disproves most of what was previously understood to be true.

This paper also aims to explore the various failure mechanisms of different configurations of filter core, comparing calculated collapse values against real tested values, with a view to understanding a method of calculating their true collapse value. As the technology is advancing, and filter elements are being used in higher temperature, higher pressure, more radioactive and more chemically aggressive environments, confidence in core collapse values and data is crucial.

INTRODUCTION

As the areas of application of diverse filter types increases, the mechanics and material science associated with the hardware and its relationship with more and more arduous process environments becomes critical to the successful and reliable operation of the filtration equipment. Structural integrity and reliability is paramount in both the validation and the ethical acceptability of the designed equipment, particularly where the filter is the last safe barrier between the process and the life environment.

Where processes are so dangerous that failure of the last safe barrier would result in catastrophe, the mechanical constraints (the subject of this paper) that dictate the design of the equipment must be well understood.

The purpose of this paper is to bring to the attention of both filter element users and manufacturers the issues around core failure, which could lead to filter element failure causing either total blockage (a danger in, say, containment venting, if the filter element core collapse resulted in a blocking of the vent route), or a system breach resulting in a discharge to atmosphere.

The paper also aims to explore the various failure mechanisms of different configurations of filter core, comparing calculated collapse values against real tested values for a given configuration of filter core, with a view to understanding a method of calculating their true collapse value. As the technology is advancing, and filter elements are being used in higher temperature, higher pressure, more radioactive and more chemically aggressive environments, confidence in core collapse values and data is crucial.

The case study was performed by the author on a number of different test specimens from a range of separate production runs, using the same batch of material. The tests were performed under identical conditions, using the same equipment for consistency; however the results yielded a diverse range of values varying up to in some cases 100%, without any obvious physical differences.

The case study has brought to light the requirement for modification of a number of standard designs, and in some cases a complete redesign has been necessary to provide an acceptable solution. In addition it has exposed the requirement and vital importance of empirical testing to support calculated values relating to core collapse.

Background

Core collapse is a key factor influencing filter element selection, and is an extremely complex issue with a number of variables and failure mechanisms. The two primary failure mechanisms that I will be exploring in this paper are buckling and circumferential collapse. It is worth noting that the additional strength, if any, which is gained from the filter pack and outer guard are not included in the scope of this report, and the filter core is considered the key structural component of the filter element.

A growing problem is that it is becoming clear that the theory behind core collapse calculations is not always supported with real tested data. In exploring this issue we have found that the calculation method is not always reflective of the true as-tested collapse value, with the calculated values being typically in excess or even an order of magnitude higher than the tested values. The above claim is supported by a case study performed by the author, which disproves most of what was previously understood to be true.

The case study for this paper was performed on a number of different test specimens from a range of separate production runs, using the same batch of material and same manufacturing processes as well as other core types (spiral welded and wedge wire). The tests were performed under identical conditions, using the same test equipment for consistency. A number of further exploratory tests were also performed to determine the effects of additional variables and their effect on core collapse. However the results yielded a diverse range of values varying up to in some cases 100%, without any obvious physical differences.

The case study has brought to light the requirement for modification of a number of standard designs, and in some cases a complete redesign has been necessary to provide an acceptable solution. In addition it has exposed the requirement and vital importance of empirical testing, and the fact that there appears to be erroneous assumptions made in the standard design/calculation methodology, to support calculated values relating to core collapse.

Filter Cores and Their Purpose

The filter core is typically the key structural component of a cylindrical sintered fibre, metal mesh, or polymer fibre/membrane filter element. The core gives the filter element structural integrity in collapse. Although it accounts for a filter element's structural integrity it is a relatively porous structure with open area typically ranging from 40 to 70%.

Filter cores enable a custom filtration solution to be produced without imposing a high differential pressure penalty, as would be the case with sintered powder solutions.

Forms of Filter Cores

Filter cores are typically manufactured from stainless steel perforated plate, tube or wire. Plain cylindrical cores are manufactured from perforated sheet and are constructed by cutting and rolling a blank of perforated sheet material, the formed material is then placed around a mandrel and the open edges or seam are joined with a tungsten inert gas seam weld (T.I.G).

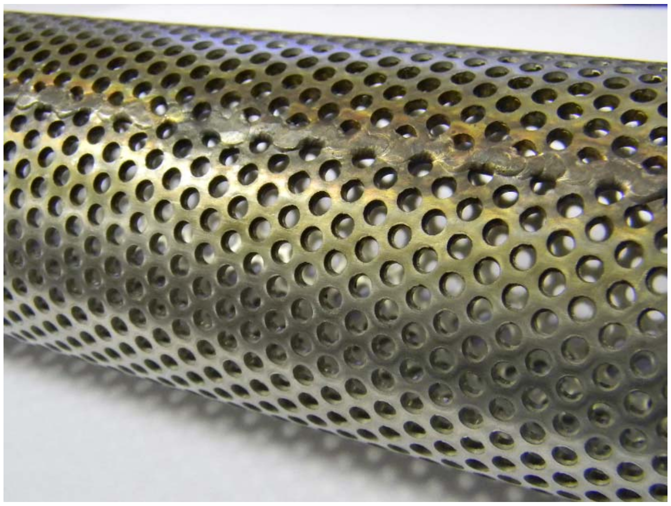

Figure 1- Typical cylindrical filter core

Spirally welded cores are manufactured from a helically cut or rolled blank of perforated material. This blank is then formed around a mandrel or placed in vee blocks, depending on the tolerances involved, and the seam is then welded using an automated or manual T.I.G welding process. This form of filter core is typically produced in large batch quantities and is welded in long lengths and cut to the required size. This form of core is said to have similar comparative strength when compared with plain cylindrical cores, however the contents of this report does not cover this comparison, and is the subject of ongoing research.

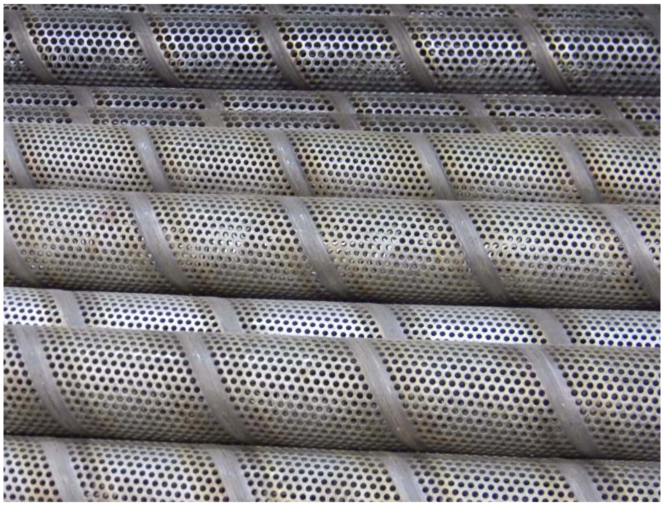

Figure 2-Typical spiral welded cores

Wedge wire slot tubes comprise of two major components; the support bars/cross rods and the profile wire. These are manufactured by loading a number of cross rods into a specialised tool which positions them in a circular array, the outer profiled wire is then wound around the arrayed cross rods and resistance welded as part of an automated process. There is a wide selection of cross rods and profiled wires that these cores can be manufactured from, the selection of which is dependent on the application concerned.

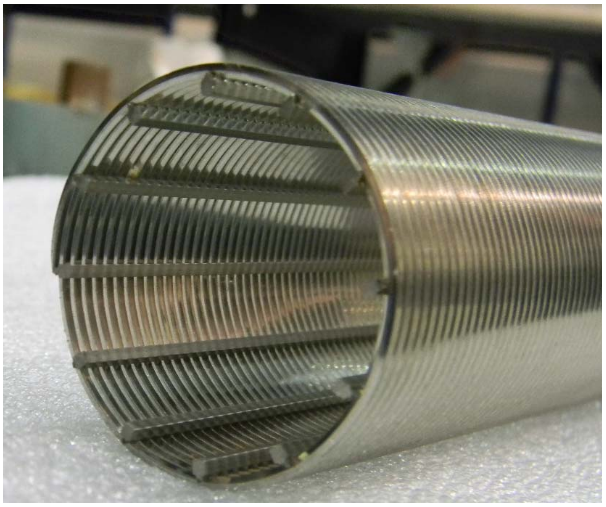

Figure 3- Typical wedge wire core

Methods of Strengthening Filter Cores

If the predominant failure mode is considered to be buckling, one of the most effective solutions in increasing a core's collapse strength is to effectively break it up into a number smaller sections using stiffening rings. This decreases the length of unsupported sections in the cores structure, providing a more stable structure. A test conducted on cores of varying lengths is included later in this paper, and clearly supports this theory.

Increasing the wall thickness is another solution which can be employed to improve the collapse strength of a filter core. This is an advisable solution if the failure mode is circumferential collapse. However with this solution there are two potential pitfalls; there is a limit on what thicknesses are manufactured and which can be rolled, and increasing the core material thickness reduces the bore diameter and increases the differential pressure at the filter outlet, the weight of the element and its suitability for volume reduction by crushing.

Another solution is to reduce the opening size/hole diameter, and opening pitch of the core material, thus increasing the ligament efficiency. But once again this, to a lesser extent than that above may also carry a differential pressure penalty due a reduction in open area.

Original Core collapse Value

The calculated core collapse value was determined using Roark's stress and strain formulas for circumferential collapse and buckling of thin walled cylinders, with a factored ligament efficiency to account for the perforations in the core material. This calculation takes into consideration the geometry of the filter core, in its installed condition and the yield strength of the material at a given temperature. The calculated collapse pressures of the test core at ambient temperature are tabulated below.

TABLE I. Calculated Core Collapse Values

Core Collapse Failure Mode	Calculated Collapse Pressure Psig (barg)
Circumferential Collapse	605 (41.7)
Buckling	1582 (109.06)

Core Inspection Methods (Out of Roundness Testing)

Due to large deviations noted between the as calculated vs the tested collapse strength values, a core measurement process was devised to provide an indication of the circularity of the sample of filter cores to be collapsed.

The core was broken up into 24 equal sectors where circularity measurements were taken. The circularity measurements were taken using a 6mm ruby tipped probe on a coordinate- measuring machine, 8 measurements were taken on the outer diameter of each sector producing a relative circle at each sector. The measurements were taken and assessed against a 0.5mm circularity tolerance, on the report the sections which this tolerance was exceeded were highlighted red and the areas in tolerance are highlighted in green.

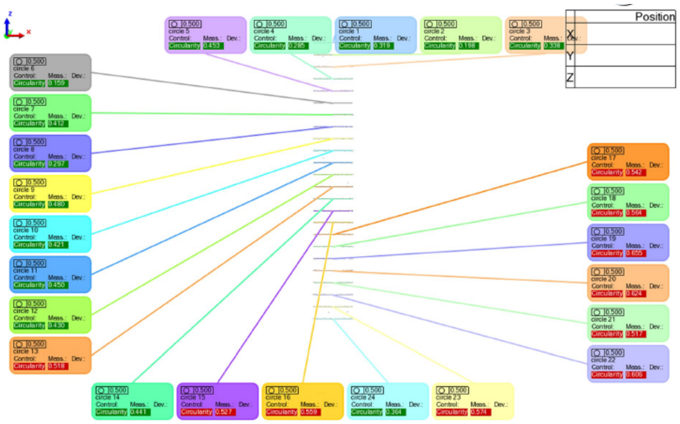

Figure 4- Typical layout of out of roundness report

TEST METHOD

As previously mentioned the strength benefits if any, attributed to the filter media and filter guard are not considered within the calculations and testing within this report. In addition welding of such items to the filter carcass would make both measurements for out of roundness both more problematic and impractical. Therefore the testing was carried out on the filter carcasses excluding the above items.

Figure 5- Collapse test rig set up

In order to make it possible to apply a differential pressure across the filter element carcass, a .010” shim was welded around the outside of the carcasses to simulate them in the fully blocked condition. Once welded the test carcasses were then bubble tested, by submerging them in an isopropanol tank, fitting them with a suitable bung fixture and pressurising them to check the welded joints for leaks. All test equipment used is calibrated and controlled in accordance with Porvair Filtration Groups internal control procedures.

The filter carcasses were then loaded into a suitable water test housing. The upstream port of the housing was connected to a manual hand pump, containing a pressure gauge to indicate the internal pump pressure. The housing was then filled with clean demineralised water, and bled of any air prior to pressurisation. Once bled the pressure inside the housing is raised in 5 bar increments and held for 2 minute intervals, until a drop in pressure signifying a collapse was detected. The water was then drained and the collapsed carcass removed, and inspected to ensure that a collapse has taken place.

Figure 6-Collapsed Filter Carcass

Figure 7-Uncollapsed carcasses

TEST PROGRAM

Test Sample 1

On the initial production run of filter elements 3 filter carcasses were picked at random and collapsed. These carcasses for test purposes were numbered 1-3, their collapse values are show in table II below. This initial test yielded relatively consistent results with the maximum deviation of 40 psig or 10% from the lowest to highest collapse value. However these values fell short by approximately 33% of the initially calculated value, which gave cause for growing concern as to what the reasoning might be for this deviation in collapse values. On the next production batch all the carcasses were measured for out of roundness to see as to whether this was accounting for the deviation between the as calculated and tested values.

TABLE II. Initial Sample Core Collapse Test Results

Core Number	Collapse pressure psig (barg)
1	440 (30.3)
2	400 (27.6)
3	420 (29)

Test Sample 2

The second batch of 14 filter carcasses were designated letters from A through to N, and were manufactured in the same production run and from the same batch of material as the previous lot. All 14 carcasses were measured for out of roundness and both the carcass with the greatest out of roundness in the middle sectors and the overall worst out of round carcass were collapsed. These two carcasses collapsed at 360 (24.82 barg) and 350 psig (24.13 barg) respectively, as displayed in table III below. It is clear that these values show an even greater deviation from the initial calculated value of 605 psig (41.4 barg) and below the requirement. There is also a noticeable difference between the collapse values of these cores and those that were previously tested, showing a maximum deviation of 90 psig or 20%.

TABLE III. Second Sample Core Collapse Test Results

Core Letter	Collapse pressure psig (barg)	Out of roundness distinguishing feature
A	360 (24.82)	Most out of round in the middle portion
M	350 (24.12)	Overall most out of round (in all areas)

Test Sample 3

In order to provide a wider spread of data, a third batch of 12 elements were manufactured using the same material as the previous two batches, and were all made in the same production run. These 12 filter carcasses were measured for out of roundness and 5 further carcasses were collapsed to see as to whether a relationship existed between the filters out of roundness and its collapse pressure. The results of this test are provided in table IV below.

TABLE IV. Third Sample Core Collapse Test Results

Core Number	Collapse pressure psig (barg)	Out of roundness distinguishing feature
3	742 (51.17)	All sectors in tolerance
5	590 (40.7)	All sectors bar the bottom in tolerance
6	529 (36.5)	Bottom half out of tolerance
9	703 (48.5)	All sectors in tolerance
11	560 (38.6)	Sectors in upper and lower portions out of tolerance

The results exhibited in the final test sample showed further deviations from the perceived trend in the last two test samples. In this test the collapse values appear to be much closer to the calculated value and in some cases in excess of this value. The highest collapse value seen was 742 psig (51.17 barg) which is approximately 22% higher than the calculated core collapse value. The deviation in collapse strength value of a good core vs a bad core can be up to 112% and is visually unnoticeable, which clearly presents a problem with the use of filter elements in safety critical environments.

It is clear that the degree of out of roundness has a significant effect on the associated strength of a filter core. However providing a correlation of this data to derive a factor which could be applied into the formula to determine the true core collapse figure, would require a more extensive test program with a larger test sample, and using a range of different geometries.

Further Exploration

Although, according to our calculations, it was indicated that the most likely probable failure mode was circumferential collapse, we conducted a further test to confirm under what condition the cores were failing. If the cores were indeed failing under circumferential collapse, the collapse value should be unaffected by the length of the core. In contrast if the predominant failure mode is buckling then the length of the core will affect the core collapse value.

In order to verify what the failure mode of these filter cores is, we conducted an additional test on a small sample of filter cores of the same diameter but of different lengths. The following test was performed under the same conditions, and using the same test equipment as specified in the (test method section of this report) above. The collapse values of these core samples are provided in table V below.

TABLE V. Core Test Sample Lengths

Filter Core Length inches (mm)	Filter Collapse Pressure psig (barg)
6” (150)	1450 (100)
10” (250)	950 (65.5)

Although it is clear from our previous test work that there is a large range of variation in the core collapse figures, that can be seen from cores of seemingly similar geometry and manufactured from the same material. I believe that these results support an opinion that, contrary to what the calculation method suggests the predominant failure mode is in fact buckling not circumferential collapse. This is due to the fact that the shorter core clearly had the highest collapse strength collapsing at 1450 psig, which is a deviation of slightly less than 100% when compared to the highest collapse value 742 psig of the full length core.

This is also further supported by the result shown from the test of the 10” core, which collapsed at 950 psig (65.5 barg) which is again above the highest value seen for the full length core, but below the 1450 psig (100 barg) shown by the 6” core.

These results support that the length of the core has an influence on the associated collapse pressure of the filter core, indicating that buckling is the more predominant failure mode

PRESENTATION OF RESULTS

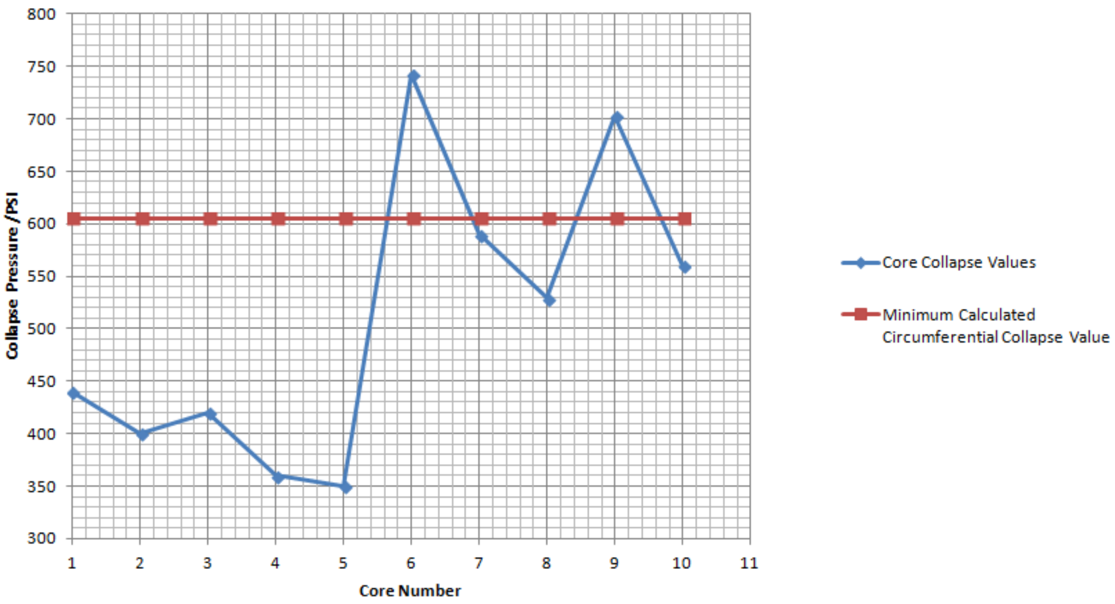

Figure 8- Results summary (all tests)

The graph above collates all of the core collapse values of all 3 of the test samples, with the core collapse values in blue, the minimum calculated collapse value is represented by the continuous red line. This graph shows a much clearer representation of the devition in core collapse values, against the calculated minimum collapse value.

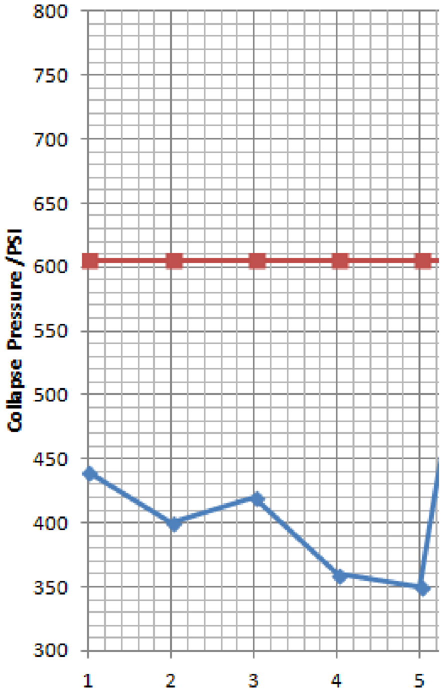

Figure 9- Snapshot of anamlous low collapse results

The snap shot above displays chronological summary of results from the first two test samples of cores that were collapsed. It is clear that these values are the lowest core collapse values found in the test program. These are significantly lower than the values obtained within the third test sample, with a maximum deviation of 112% as highlighted in previous sections. Other than the differences in out of roundness from batches 2 to 3, there is no clear physical characteristic which gives an indication as to why the core collapse values are so starkly different.

On-Going Work

It is the intention of the company to not only attempt to establish the most influential factors in core collapse pressure, but to also establish definitely the mode of collapse (circumferential/oblique buckling) and to examine the effects of temperature on core collapse as it seems clear that geometry at the macro level (out of roundness) is a significant factor. Therefore it is possible that at high temperatures there may be issues other than loss of strength in the core material) perhaps distortion leading to phenomena similar to the effects of out of roundness.

CONCLUSIONS

This paper is presented as an alarm bell to both manufacturers and users of metal filters in extreme conditions to ensure that it is understood that the routine methodology for establishing the collapse strength of cores at particular conditions, is for whatever reason erroneous and that safety factors must be built into core construction (based on prior test work) to accommodate this anomalous behaviour, until the factors affecting core collapse behaviour are fully understood and these critical components to public safety can be modelled with certainty.