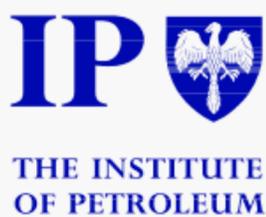


SPECIFICATION FOR SIMILARITY FOR
API/IP 1581 AVIATION JET FUEL FILTER/SEPARATORS

API/IP SPECIFICATION 1582



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API/IP 1581 AVIATION JET FUEL FILTER/SEPARATORS

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February 2001

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FOREWORD

This publication, prepared jointly by the Institute of Petroleum Aviation Committee and the American Petroleum Institute Aviation Technical Services Sub-Committee, is intended to provide the industry with a specification for the qualification by similarity of filter/separators used in systems that handle jet fuel.

These specifications are for the convenience of purchasers in ordering, and manufacturers in fabricating, filter/separators. They are not in any way intended to prohibit either the purchase or manufacture of filter/separators meeting other requirements.

Any manufacturer wishing to offer filter/separators conforming to these specifications is responsible for complying with all the mandatory provisions of these specifications.

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Although it is hoped and anticipated that this publication will assist both the manufacturers and purchasers of filter/separators, the Institute of Petroleum and the American Petroleum Institute cannot accept any responsibility, of whatever kind, for damage or loss, or alleged damage or loss, arising or otherwise occurring as a result of the application of the specifications contained herein.

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1

INTRODUCTION AND SCOPE

1.1 INTRODUCTION

Testing to qualify the performance of filter/separator systems is specified in API/IP 1581. A critical performance test specified in API/IP 1581 is the single element test. This is a test of the intrinsic ability of filtration system components to remove dirt and water from jet fuel. A second critical test is the full-scale test. This is a test of the ability of systems of components, which meet single element test criteria, to remove dirt and water under the flow conditions present in commercial-scale systems. Because the scale and complexity of full-scale testing place significant demands on testing resources, it is desirable to minimize the number of full-scale tests required to qualify a range of vessels and filter/separators.

Similarity is the methodology developed to minimize the number of full-scale tests. The concept is that full-scale testing is not needed if a candidate filtration system can be shown to be sufficiently similar to a system already qualified (by full-scale testing) to support the expectation that full-scale testing would meet API/IP 1581 requirements. Such a system is said to be "qualified to API/IP 1581 by similarity".

1.2 SCOPE

This publication specifies the minimum requirements for a filter/separator system to qualify to API/IP 1581 by similarity.

This publication applies to two-stage (filter and separator) and the filter/separator stages of multi-stage

filter/separator systems. This publication does not apply to monitor and/or prefilter stages that may be present in multi-stage systems.

1.3 REFERENCED PUBLICATIONS

The following publications are cited in this publication, the latest available edition of each referenced publication applies:

API/IP 1581 *Specification and qualification procedures for aviation jet fuel filter/separators*

1.4 ABBREVIATIONS

The following abbreviations are used within this publication:

ft/sec	feet per second
gpm	U.S. gallons per minute
lps	litres per second
m/sec	metres per second

1.5 DEFINITIONS

The following terms are used within this publication:

$\Sigma S_{Ae}/A_{cv}$ the ratio of the sum of the effective (without end caps) surface areas of all elements to the inside cross-sectional area of the vessel.

$\Sigma A_e/A_{cv}$ the ratio of the sum of the cross-sectional areas of all elements to the inside cross-sectional area of the filtration vessel.

candidate system: the subject of this specification. A candidate system has not been tested to API/IP 1581 4th Edition. The proper application of this specification documents that a candidate system either qualifies to API/IP 1581 by similarity or fails to qualify to API/IP 1581.

class of layout: general arrangements of filter and separator elements as defined in 2.4.

mean linear flow rate: the "flow per inch" for filter/coalescer elements.

qualified system: a filtration system tested to and meeting API/IP 1581 4th Edition requirements.

void volume: the volume of a vessel minus the volume of all elements. Elements are considered as solid objects for this purpose.

void volume ratio: the ratio of vessel void volume to vessel volume.

2

SIMILARITY SPECIFICATION

2.1 GENERAL

Any filter/separator system qualified in accordance with API/IP 1581 will allow qualification by similarity with systems of other sizes, provided the requirements of 2.2 - 2.9 are met. If these requirements are not entirely satisfied, then a candidate system may be qualified if the requirements of 2.10 are met.

If the requirements of 2.2 - 2.9 or 2.10 are not met, then the system shall not qualify by similarity. The candidate system must be qualified to the requirements of API/IP 1581 by full-scale testing.

2.2 CONFIGURATION

The configuration of the candidate and qualified systems shall be the same. Systems are defined as having the same configuration when the candidate and qualified systems have the same:

- (a) Orientation (vertical or horizontal).
- (b) General flow pattern (side-by-side or end-opposed).
- (c) Relative sump location and volume. Sump volumes need not scale with flow rate if a water defence system (API/IP 1581 4th Edition p. 3.2.4.5) is present.
- (d) Relative positions for inlet and outlet connections.

2.3 INTERIOR GEOMETRY

The interior geometry of the candidate system shall be essentially similar to that of the qualified system. The dimensions 2.3 (a) - (d) shall not be less in the candidate system than in the qualified system.

- (a) Minimum spacing between filter/coalescer elements.
- (b) Minimum spacing between separator elements.
- (c) Minimum spacing between filter/coalescer and separator elements.
- (d) Minimum distance between elements and vessel wall.

2.4 ELEMENT LAYOUT

The element layout of the candidate system shall belong to the same class as the qualified system. The classes of element layout recognized by this specification are divided into two general flow patterns: side-by-side (Figures 1-3) and end-opposed (Figures 4-5).

2.4.1 Side-by-side classes

- (a) **Side-to-side:** The identifying characteristic of this class (Figure 1) is that the coalescer elements

are grouped on one side of the vessel and the separator elements on the other side. A line or shallow arc separates the coalescer and separator stages. Systems using this design may have either vertical or horizontal orientation. When side-to-side flow occurs in systems oriented horizontally, the effect of gravity on water dropout separates into different classes the cases where flow is 1) aligned with, 2) opposed to, and 3) transverse to the attraction of gravity.

(c) Engaged: Layouts intermediate between side-to-side and concentric fall in these classes (Figure 3). Systems using this design may have either vertical or horizontal orientation. When engaged flow occurs in vessels oriented horizontally, the effect of gravity on water dropout separates into different classes the cases where flow is 1) aligned with, 2) opposed to, and 3) transverse to the attraction of gravity.

(b) Concentric: The identifying characteristic of this class (Figure 2) is that the filter/coalescer stage surrounds the separator stage.

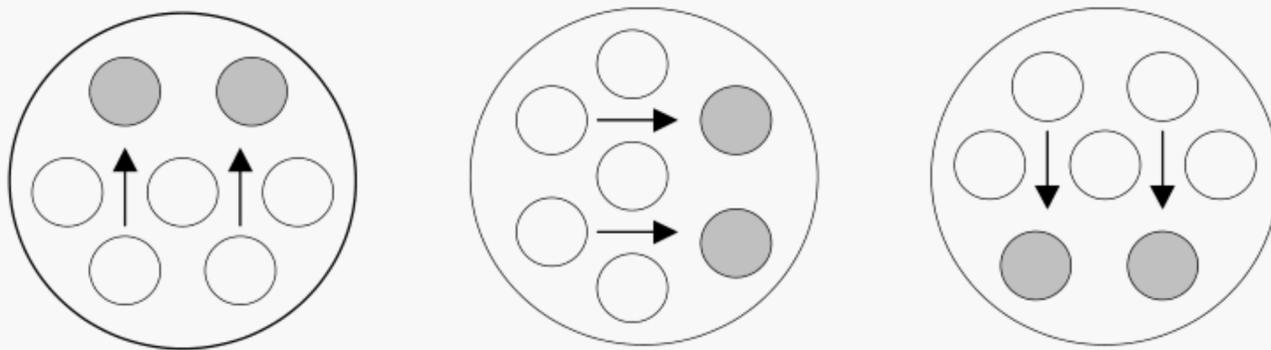


Figure 1 - Side-by-side classes of element layout:¹ Side-to-side²

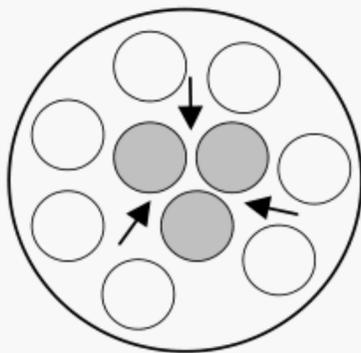


Figure 2 - Side-by-side classes of element layout: Concentric³

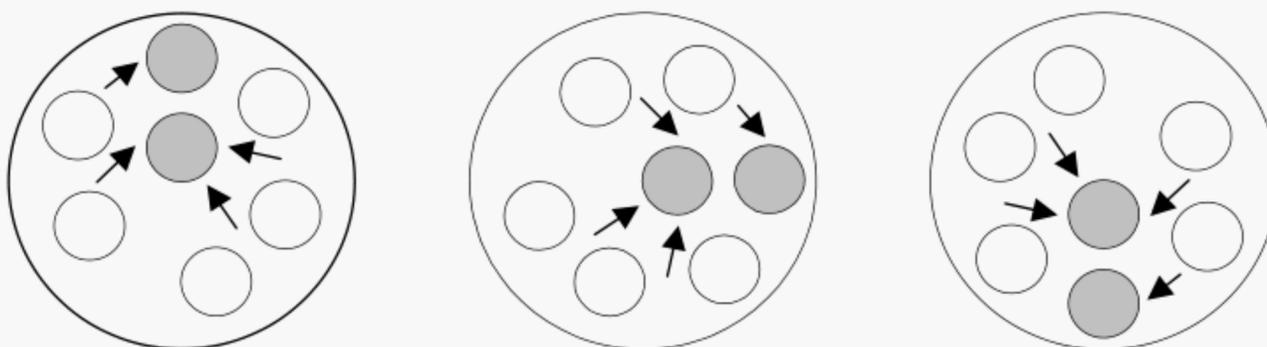


Figure 3 - Side-by-side classes of element layout: Engaged²

¹ The open circles are coalescer elements. The separator elements are shaded.

² End view. Note that the three drawings depict a single element layout (class) in vertical orientation but different layouts in horizontal orientation because of the dynamics of water dropout.

³ End view.

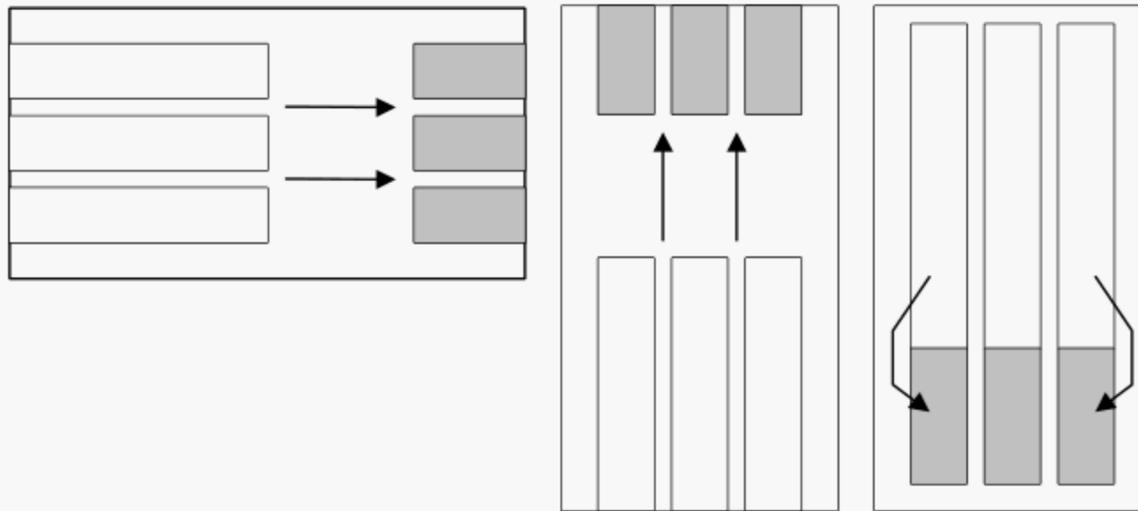
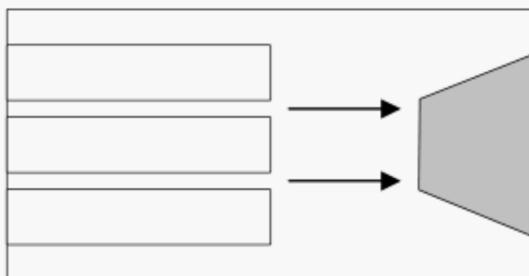


Figure 4 - End-opposed classes of element layout:⁴ Cylindrical separators

⁴ Side view. The open rectangles are coalescer elements. The filled rectangles are separator elements.

2.4.2 End-opposed classes

- Vertical systems having elements in the end-opposed layout populate different classes (Figure 4) when the flow is 1) opposed to and 2) aligned with the attraction of gravity.
- Systems having a single, non-cylindrical-shaped (or "basket") separator (Figure 5) populate a different class than systems having cylindrical-shaped separators.



**Figure 5 - End-opposed classes of element layout:
Non-cylindrical separator**

2.5 RATED FLOW

The candidate system shall have a rated flow equal to or less than the flow of the qualified system.

2.6 MODEL TYPE

The filter/coalescer and separator elements shall be the same models in both candidate and qualified systems. Elements shall be identical with respect to construction and media but may vary in length and end-cap type (open-ended/threaded base).

The outside diameter of separator elements may vary.

The length-to-outside-diameter ratio of the separator elements (each stack of separator elements when stacked) in the candidate system shall not exceed that of the qualified system.

2.7 MEAN LINEAR FLOW RATE

The mean linear flow rate of the filter/coalescer elements of the candidate system shall not exceed that of the qualified system.

2.8 LIQUID ENTRANCE VELOCITY

The liquid entrance velocity (m/s) at the outer surface of the separator elements in the candidate system shall not exceed that of the qualified system. The velocity can be calculated from the following equation (in SI units):

$$V = 1\,000\,Q/AN$$

In customary systems, this translates to:

$$V = 0,00223Q/AN$$

where:

- V is the average liquid entrance velocity at the outer surface of each separator element in cm per second (feet per second).
- Q is the rated flow of the system in lps (gpm).
- A is the surface area (circumference x length) of each separator element in cm² (ft²).
- N is the number of separator elements.

2.9 ELEMENT/VESSEL RATIOS

The void volume ratio of the candidate system shall not be less than the qualified system. In addition:

- (a) For the side-by-side general flow pattern: $\Sigma S_{A_e}/A_{cv}$ shall not exceed that of the qualified system.
- (b) For the end-opposed general flow pattern: $\Sigma A_e/A_{cv}$ shall not exceed that of the qualified system.

2.10 SIMPLIFIED FLOW MODEL

Candidate systems that meet 2.2 - 2.9 qualify as meeting API/IP 1581 by similarity. An alternative qualification is permitted for candidate systems that would otherwise fail because they do not meet all of 2.2 (c), 2.2(d), 2.3 and 2.4.

If the candidate system meets 2.2 (a), 2.2 (b), 2.5 - 2.9, 2.10 (a) and 2.10 (b) then it shall qualify as meeting API/IP 1581 by similarity.

- (a) The maximum internal flow velocities of the candidate system shall not be greater than the qualified system.
- (b) The residence times in the candidate system shall not be less than the qualified system.

Compliance with 2.10 (a) and (b) may be demonstrated by application of the Simplified Flow Model, defined in Section 3, or by agreement between supplier and purchaser using any equivalent or more rigorous flow model.

3

SIMPLIFIED FLOW MODEL METHODOLOGY

3.1 GENERAL

The Simplified Flow Model (SFM) is provided as a model for calculating flow parameters to establish that candidate and qualified systems are similar when conventional similarity criteria fail to establish similarity. The SFM is not required for determining similarity. It provides flexibility in qualifying by similarity systems that, otherwise, would require full-scale testing.

The Simplified Flow Model (SFM) is a simple model for determining flow parameters between the coalescer and separator elements in a two-stage filter/separator system. The modelling assumptions and details are described in 3.2 - 3.3.

An Excel spreadsheet that automates the steps in 3.3 is available from the API.

3.2 DESCRIPTION

The SFM assumes that the fluid is a single phase and that the flow is evenly distributed over all elements; i.e. there are minimal flow mal-distributions due to element variation and dirt loading. It also assumes that the velocity between elements at any cross-section perpendicular to flow is uniform.

3.3 SFM METHOD

The model functions by dividing the filter/separator system into zones (based on vessel cross-section).

Each zone is comprised of the three closest elements or two closer elements and the wall. The length of a zone is the average length of the elements that comprise its borders. The flow through each zone is summed by assuming:

- (a) The flow into the filter/separator system is equal through each filter.
- (b) The flow exits each filter/coalescer element evenly (radially).
- (c) The flow into each separator is the same.
- (d) The radial distribution of flow into separators is evenly distributed.

The summed flows are used to calculate linear flow velocities through each zone and residence time in each zone.

Example calculations of the SFM are detailed in Annex A and B.

ANNEX A

SIMPLIFIED FLOW MODEL SIDE-BY-SIDE CONFIGURATION

A manual method for calculating linear flow velocities and residence times in a side-by-side filtration system (Figure 6) by the Simplified Flow Model follows:

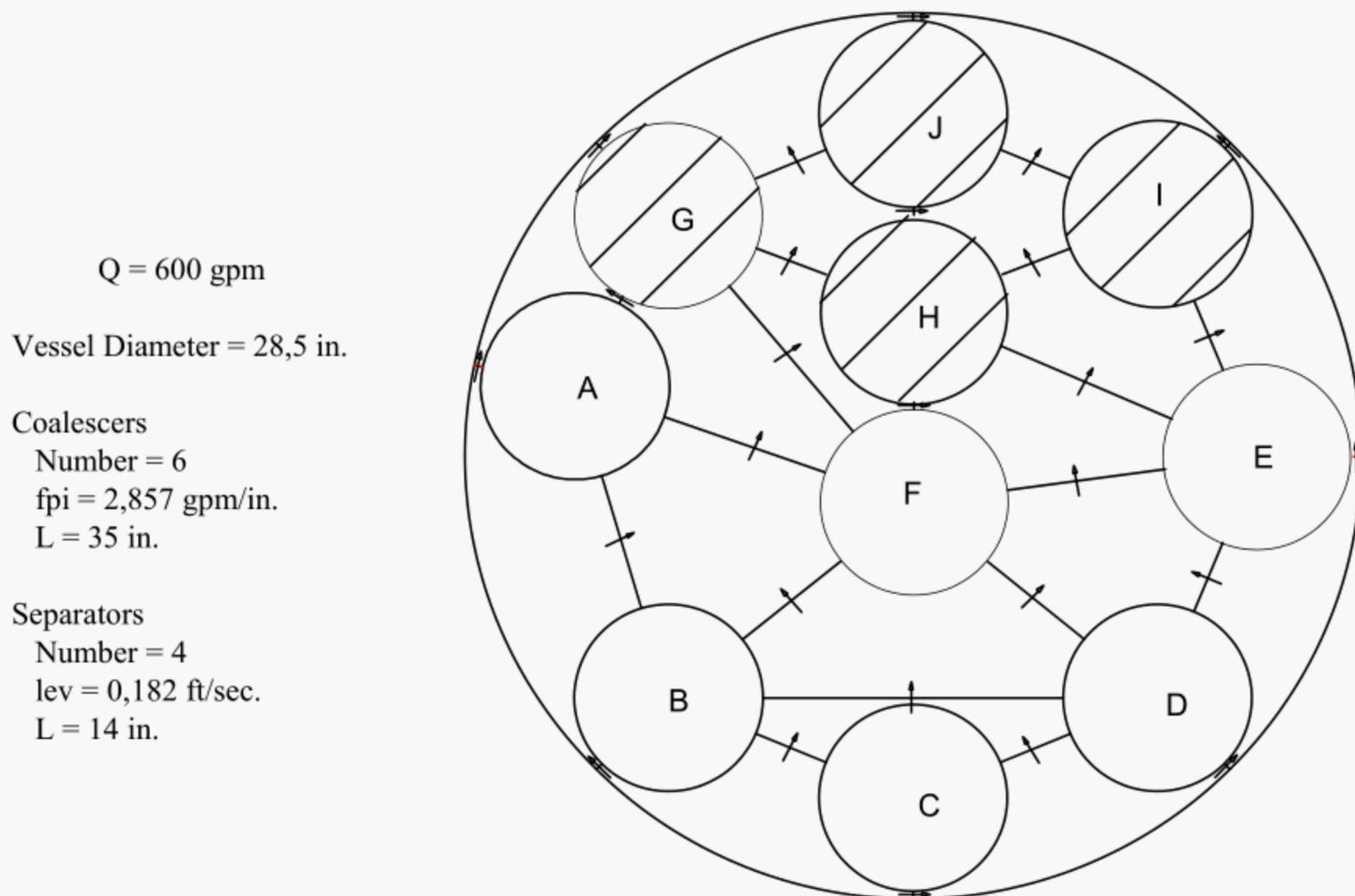


Figure 6 - Side-by-side similarity example

A.1 LABELLING CONVENTIONS

- An *element* is a filter/coalescer or separator. It shall be identified by a capitalized letter, e.g. A.
- A *segment* is the distance between two elements. It shall be identified by the two letters that the segment links, e.g. AB, BC, etc. The segment between the wall and an element shall be identified by the letter w and the element to which it is connected, e.g. wA, wE etc.
- A *line* is a series of segments that start at the wall of the vessel and extend to the wall on the other side of the vessel. It is defined by the wall and the elements connected by the line, e.g. wEFAw, wDBw, etc.
- A *region* is a series of 3 segments that define a triangular region between elements or the wall of the vessel and elements. It is defined by the elements defining the region, beginning and ending with the first element of the region, e.g. EFDE, wABw
- Each segment has a *velocity vector* shown by an arrow. The velocity calculated below is positive in the direction of the velocity vector.

A.2 SEGMENTING THE VESSEL

The diagram of the vessel cross-section should be rotated so that the filter/coalescers are predominantly on the bottom. Locate the elements by the distance from the centre of the vessel and the angle from the horizontal diameter. Table 1 shows this for Figure 6.

Lines shall be drawn as follows:

- Starting at the centre of the vessel, draw a horizontal line across the vessel. Select the elements that touch the horizontal line. This becomes the first line. In Figure 6, this line is wEFAw. Subsequent lines are drawn by selecting the next elements closest to the wall and line, e.g. D and B. A line is drawn between these elements. All elements touching the line are included, e.g. wDBw. Also included are elements between the previous line and this line, e.g. wIHGw. This process is continued until no elements remain that are not associated with a line. In the case where

only one element remains, e.g. element C or J, then a line will be defined by the first and last elements of the line next to the element and the element, e.g. wDCBw or wIJGw.

Regions shall be drawn as follows:

- Select two adjacent lines, e.g. wEFAw and wDBw. Define the wall regions joining these lines, e.g. wEDw and wABw. Starting on the right hand side of the longest line, i.e. the line with the most elements, or the line closest to the vessel centre if lines are equal, divide the region between the lines into triangular segments. For consistency, select the first element, move to the next element on the line, move to the element on the next line, then move to the first element, e.g. EFDE. Select the element on the second line that was chosen above, move to the next element on the same line, move to the next unchosen element of alternate line, then move to first element, DBFD. Continue the process until the area between the two lines is broken into regions. On lines next to the vessel wall, e.g. wDCBw, the regions are defined between the line and wall, e.g. wDCw and wCBw.

Table 1 - Location of elements

ID	Type	Radius (in.)	Angle (degrees)
A	FC	11	168
B	FC	11	225
C	FC	11	270
D	FC	11	315
E	FC	11	0
F	FC	1,5	270
G	S	11	135
H	S	4,75	90
I	S	11	45
J	S	11	90

A.3 SEGMENT LENGTH AND FLOW RATE

Calculate or measure the length of each segment. The segments can be further classified as between two filter/coalescers, between two separators, or mixed i.e. between a filter/coalescer and separator. For Figure 6, the lengths are shown in Table 2.

The flow rate between each segment on a line is assumed proportional to its length. To calculate the flow rate across a line, follow the following procedure:

- *Step 1* – Sum the flow rate from all filter/coalescers below the line. From this, subtract the flow rate of all separators below the line.
- *Step 2* – For each element on the line, calculate or measure the angle defining the amount of the element that is below the line. For example, choosing element F on line wEFAw, the angle is defined by AFE. This angle (in degrees) divided by 360 is the fraction of flow that flows into or out of the element below the line. Sum the flows from the fraction below the line of all filter/coalescers on the line. Subtract from this the flow rate from the fraction of all separators on the line. Add this to the result from Step 1. This is the total flow rate across the line.
- *Step 3* – Sum the lengths of all segments on the line. The flow rate across each segment is the length of the segment divided by the total length of segments on the line multiplied by the total flow rate across the line.

Starting at a wall region, a series of mass balances can

be performed to determine the flow rates of the segments that are not on lines, e.g. segment ED, FD etc. To do this, select a region, e.g. wEDw. Calculate the flow rate into or out of the fraction element in the region using the procedure of Step 2 above. Using the convention that flow into a region is negative and out of a region is positive, add the flow rate of the segments with flow rate leaving the region and flow rate from the fraction of separator(s) in the region. From this subtract the flow rate of the segments with flow entering the region and the flow rate from the fraction of filter/coalescer(s) in the region. The result is the flow rate across the unknown segment. Continue this process until the flow rates across all segments are known.

The velocity for each segment is then calculated as follows:

- *Step 1* – Calculate the area by multiplying the length of the segment by the sum of the lengths of the two elements linked by the segment and divide by 2.
- *Step 2* – Divide the flow rate across the segment by the area calculated in Step 1. (Note: Use consistent units so that velocity results in units of ft/sec.)

The results of these calculations for Figure 6 are given in Table 3.

Table 2 - Lengths of segments

Segment	FC/FC (in.)	Mixed (in.)	S/S (in.)
AB	4,497		
AF	5,407		
AG		0,248	
BC	2,419		
BD	9,556		
BF	3,996		
CD	2,419		
DE	2,419		
DF	3,996		
EF	5,102		
EH		5,982	
EI		2,419	
FG		6,107	
FH		0,250	
GH			2,347
GJ			2,419
HI			2,347
HJ			0,250
IJ			2,419
wA	0,250		
wB	0,250		
wC	0,250		
wD	0,250		
wE	0,250		
wG			0,250
wI			0,250
wJ			0,250

Table 3 - Flow rates and velocities for segments

Segment	Length (in.)	Flow (gpm)	Velocity (ft/sec.)
wE	0,250	10,295	0,540
EF	5,102	210,095	0,378
AF	5,407	222,648	0,378
wA	0,250	10,295	0,540
wD	0,250	4,350	0,228
BD	9,556	166,299	0,160
wB	0,250	4,350	0,228
CD	2,419	58,150	0,220
BC	2,419	58,150	0,220
wI	0,250	16,246	1,490
HI	2,347	152,504	1,490
GH	2,347	152,504	1,490
wG	0,250	16,246	1,490
IJ	2,419	77,504	0,735
GJ	2,419	77,504	0,735
DE	2,419	56,555	0,214
wC	0,250	0,000	0,000
AB	4,497	59,889	0,122
AG	0,248	20,742	1,094
wJ	0,250	0,000	0,000
EI	2,419	21,576	0,117
DF	3,996	103,540	0,238
BF	3,996	112,759	0,259
EH	5,982	175,273	0,384
FH	0,250	-38,541	-2,020
FG	6,107	238,286	0,511
HJ	0,250	0,000	0,000

A.4 RESIDENCE TIMES

The average time a water droplet spends in a region can affect settling and separator efficiency. This is proportional to the average time the fuel spends in the region. The residence time is defined as the volume of fuel in the region divided by the flow rate into a region. The volume of the region is calculated by:

- *Step 1* – Calculate the area of the triangle defining the region, e.g. DBCD. Subtract the sum of areas of elements that fall inside the region. (This can be done by measuring the angle of each element within the region dividing by 360 and multiplying by the total area of the element.) In the case of a wall-bounded region, calculate the area of the pie defined by lines through the elements from the centre of the vessel. Then subtract the triangle maintained by the centres of the two elements and the centre of the vessel. Finally, subtract the areas of elements within the region.
- *Step 2* – Calculate the average length of the region by adding the length of the 3 elements defining the region and dividing by 3.
- *Step 3* – Multiply the results of Step 1 and Step 2.

Calculate the flow into the region by adding the flow rates into the region across segments and the fraction of flow from filter/coalescers within the region.

Divide the volume by the flow rates into the region to determine the residence time. The residence time for Figure 6 is given in Table 4.

Table 4 - Residence times in regions

Region	FC/FC (sec.)	Mixed (sec.)	S/S (sec.)
DBCD	0,598		
DFBD	1,460		
EFDE	1,136		
EHFE		1,078	
FABF	1,405		
FGAF		0,592	
HGFH		0,364	
IHEI		0,752	
IJHI			0,478
JGHJ			0,478
wAGw		0,925	
wBAw	4,104		
wCBw	2,809		
wDCw	2,809		
wEDw	2,626		
wGJw			0,749
wIEW		1,947	
wJIw			0,749

ANNEX B

SIMPLIFIED FLOW MODEL END-OPPOSED CONFIGURATION

A manual method for calculating linear flow velocities and residence times in an end-opposed filtration system (Figure 7) by the Simplified Flow Model follows:

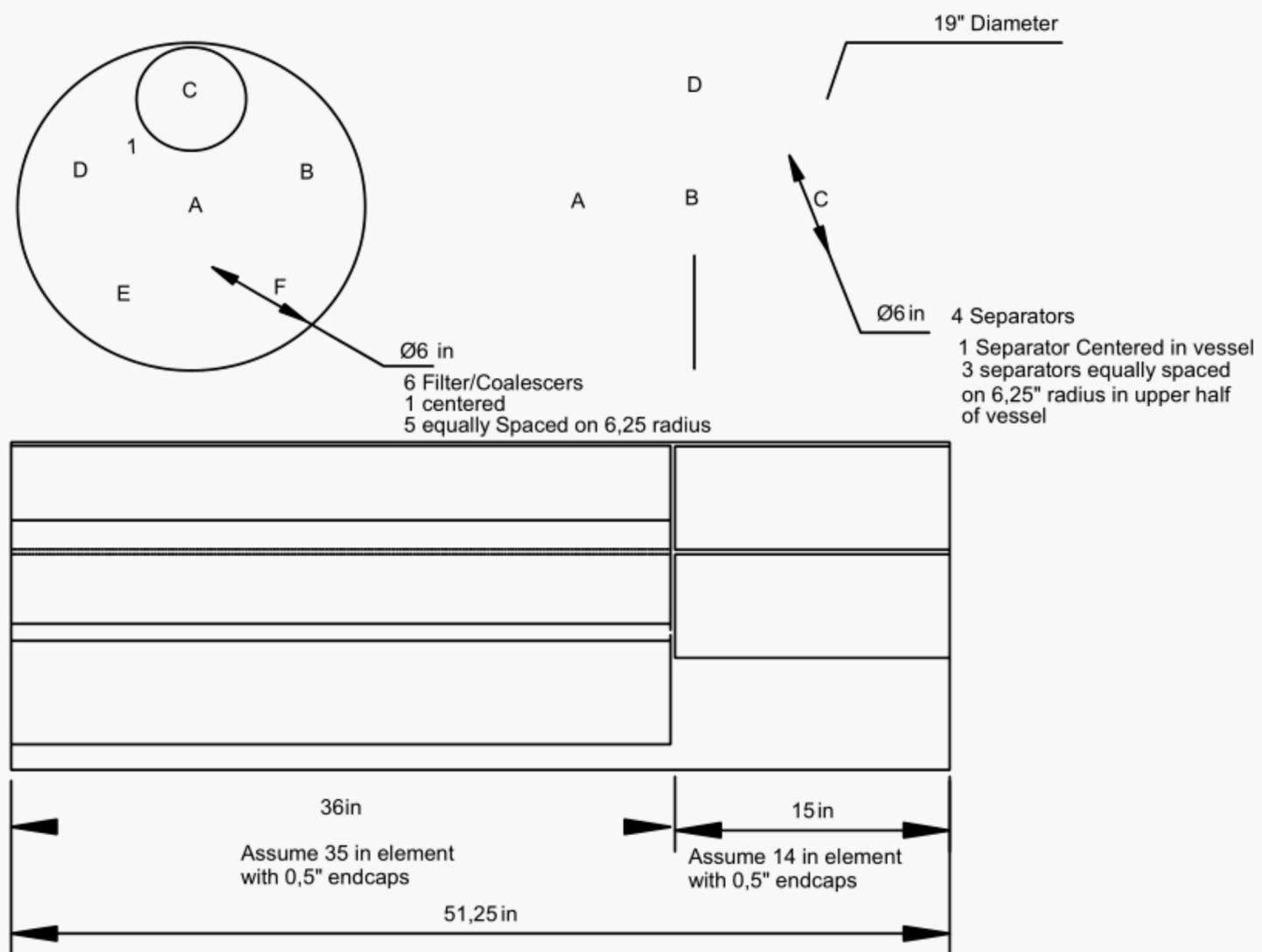


Figure 7 - End-opposed configuration

B.1 LABELLING CONVENTIONS

- An *element* is a filter/coalescer or separator. It shall be identified by a capitalized letter, e.g. A
- A *segment* is the distance between two elements. It shall be identified by the two letters that the segment links, e.g. AB, BC, etc. The segment between the wall and an element shall be identified by the letter w and the element to which it is connected, e.g. wA, wD etc.
- A *line* is a series of segments that start at the wall of the vessel and extend to the wall on the other side of the vessel. It is defined by the wall and the elements connected by the line, e.g. wCBAw (separators), wFEw (filter/coalescers), etc.
- A *region* is a series of 3 segments that define a triangular region between elements or the wall of the vessel and elements. It is defined by the elements defining the region, beginning and ending with the first element of the region, e.g. CBDC (separators), wCDw.
- Each segment has a *velocity vector* shown by an arrow. The velocity calculated below is positive in the direction of the velocity vector.

B.2 SEGMENTING THE VESSEL

The diagram of the cross-section of the vessel should be rotated so that the separators are predominantly on the top. Locate the elements by the distance from the centre of the vessel and the angle from the horizontal diameter. Table 5 shows this for Figure 7. The view of the location of the elements shall be from a plane located between the filter/coalescers and the separators. The location of the elements is looking from that plane to the separators or filter/coalescers.

Lines shall be drawn in the separator section as follows:

- Starting at the centre of the vessel, draw a horizontal line across the vessel. Select the elements that touch the horizontal line. This becomes the first line. For separators in Figure 7, this line is wCBAw. Subsequent lines are drawn by selecting the next elements closest to the wall and line. A line is drawn between these elements. All elements touching the line are included. Also included are elements between the previous line and this line. This process is continued until no elements remain that are not associated with a line. In the case where only one element remains, e.g. separator element D, then a line will be defined by the first and last elements of the line next to the element and the element, e.g. wCEAw.

Regions shall be drawn as follows:

- Select two adjacent lines, e.g. wCBAw and wCDAw. Define the wall regions joining these lines, e.g. wCDw and wDAw. Starting on the right hand side of the longest line, i.e. the line with the most elements, or the line closest to the vessel centre if lines are equal, divide the region between the lines into triangular segments. For consistency, select the first element, move to the next element on the line, then move to the element on the next line, then move back to the first element, e.g. CBDC (separators). Select the element on the second line that was chosen above, move to the next element on the same line, then move to the next unchosen element of the other line, then move back to the first element, DABD (separators). Continue the process until the area between the two lines is broken into regions. On lines next to the vessel wall, e.g. wCDAw, the regions are defined between the line and wall, e.g. wDCw and wDAw (separators).

Table 5 - Location of separators and filter/coalescers

Separators			Filter/Coalescers		
Element	Radius (in.)	Angle (degrees)	Element	Radius (in.)	Angle (degrees)
A	6,25	180	A	0	0
B	0	0	B	6,25	18
C	6,25	0	C	6,25	90
D	6,25	90	D	6,25	162
			E	6,25	234
			F	6,25	306

Similar segments and regions are drawn for the filter/coalescers.

Table 6 - Lengths for segments

Filter/Coalescers		Separators	
Segment	Length (in.)	Segment	Length (in.)
wB	0,2500	wC	0,2500
AB	0,2500	BC	0,2500
AD	0,2500	AB	0,2500
wD	0,2500	wA	0,2500
wF	0,2500	CD	2,8388
EF	1,3473	AD	2,8388
wE	0,2500	wB	6,5000
BC	1,3473	wD	0,2500
CD	1,3473	BD	0,2500
BF	1,3473		
DE	1,3473		
AF	0,2500		
AE	0,2500		
wC	0,2500		
AC	0,2500		

B.3 SEGMENT LENGTH AND FLOW RATE

Calculate or measure the length of each segment. For Figure 7, the lengths are shown in Table 6.

The flow rate between each segment on a line is assumed proportional to its length. To calculate the flow rate across a line, follow the following procedure:

Separator Section:

- *Step 1* – Calculate the areas of each region. For regions adjacent to the wall, the area can be calculated by calculating the area of the pie from the centre of the vessel and lines going through the centre of the elements to the wall. This is the angle

of the pie divided by 360 and multiplied by the cross-sectional area of the vessel. Subtract the area of the triangle from the centre of the vessel and the centres of the two elements. Finally, subtract the area of the elements within the regions.

- *Step 2* – For each line, calculate the flow across the line. Assuming plug flow across the region between the filter/coalescers and separators, the flow into the region below the line is the total flow for the vessel multiplied by the sum of area in regions below the line divided by the total area of the regions in the separator section. Subtract from that the flow into each separator below the line. Finally, subtract the flow rate per separator multiplied by the fraction of the separator below the line for each separator on the line. This is the flow across the line. For example, for line wCBAw, the flow across the line is:

Total Flow for the vessel (600 GPM) X $\sum(\text{Areas } wABw \text{ \& } wCBw) / \sum(\text{Areas } wABw, wCBw, wADw, wDCw, CDBC, DABD) - \text{Flow into separators below line (None)} - \text{Flow into separators A, B, C below the line } (0,5 \times 150 + 0,5 \times 159 + 0,5 \times 150 \text{ gpm}).$

- *Step 3* – Sum the lengths of all segments on the line. The flow rate across each segment is the length of the segment divided by the total length of segments on the line multiplied by the total flow rate across the line.

Starting at a wall region, a series of mass balances can be performed to determine the flow rates of the segments that are not on lines, e.g. segment BD. To do this, select a region, e.g. CBDC. Calculate the flow rate into or out of the fraction of the separator in the region. Using the convention that flow into a region is negative and out of region is positive, add the flow rate of the segments with flow rate leaving the region and flow rate from the fraction of separator(s) in the region. Also, add the total flow multiplied by the area of the region divided by the sum of all regions in the separator section. From this, subtract the flow rate of the segments with flow entering the region. The result is the flow rate across the unknown segment. Continue this process until the flow rates across all segments are known.

The velocity for each segment is then calculated as follows:

Step 1 – Calculate the area by multiplying the length of the segment by the length of a separator.

Step 2 – Divide the flow rate across the segment by the area calculated in Step 1. (Note: Use consistent units so that velocity results in units of ft/sec.)

The results of these calculations for Figure 7 are given in Table 7.

Filter/Coalescer Section:

- *Step 1* – Calculate the areas of each region. For regions adjacent to the wall, the area can be calculated by calculating the area of the pie from the centre of the vessel and lines going through the centre of the elements to the wall. This is the angle of the pie divided by 360 and multiplied by the cross-sectional area of the vessel. Subtract the area of the triangle from the centre of the vessel and the centres of the two elements. Finally, subtract the area of the elements within the regions.

- *Step 2* – For each line, calculate the flow across the line. Add all the flows from filter/coalescers below the line, F_F . Assuming plug flow across the region between the filter/coalescers and separators, the flow from the region below the line is the total flow for the vessel multiplied by the sum of area in regions below the line divided by the total area of the region in the filter/coalescer section. Subtract this from F_F . Finally, add the flow rate per filter/coalescer multiplied by the fraction of the filter/coalescer below the line for each filter/coalescer on the line. This is the flow across the line.

- *Step 3* – Sum the lengths of all segments on the line. The flow rate across each segment is the length of the segment divided by the total length of segments on the line multiplied by the total flow rate across the line.

Starting at a wall region, a series of mass balances can be performed to determine the flow rates of the segments that are not on lines, e.g. segment BF. To do this, select a region, e.g. wBFw. Calculate the flow rate out of the fraction of the filter/coalescers in the region. Using the convention that flow into a region is negative and out of a region is positive, add the flow rate of the segments with flow rate leaving the region and subtract flow leaving the region across segments. Add the total flow multiplied by the area of the region divided by the

sum of all regions in the filter/coalescer section. Finally, subtract the flow from the fraction of each filter/coalescer in the region. The result is the flow rate across the unknown segment. Continue this process until the flow rates across all segments are known.

The velocity for each segment is then calculated as follows:

Step 1 – Calculate the area by multiplying the length of the segment by the length of a filter/coalescer.

Step 2 – Divide the flow rate across the segment by the area calculated in Step 1. (Note: Use consistent units so that velocity results in units of ft/sec.)

The results of these calculations for Figure 7 are given in Table 7.

Table 7 - Flow rates and velocities of separator and filter/coalescer sections

Filter/Coalescers			Separators		
Segment	Flow Rate (gpm)	Velocity (ft/sec.)	Segment	Flow Rate (gpm)	Velocity (ft/sec.)
wB	0,0000	0,0000	wC	31,1920	2,8608
AB	0,0000	0,0000	BC	31,1920	2,8608
AD	0,0000	0,0000	AB	31,1920	2,8608
wD	0,0000	0,0000	wA	31,1920	2,8608
wF	0,0000	0,0000	CD	-24,8180	-0,2004
EF	-26,6170	-0,1812	AD	-24,8180	-0,2004
wE	0,0000	0,0000	wD	0,0000	0,0000
BC	26,617	0,1812	BD	0,0000	0,0000
CD	26,6170	0,1812	wB	0,0000	0,0000
BF	-26,6170	-0,1812			
DE	-26,6170	-0,1812			
AF	0,0000	0,0000			
AE	0,0000	0,0000			
wC	0,0000	0,0000			
AC	0,0000	0,0000			

B.4 RESIDENCE TIMES

The average time a water droplet spends in a region can affect settling and separator efficiency. This is proportional to the average time the fuel spends in the region. The residence time is defined as the volume of fuel in the region divided by the flow rate into a region. The volume of the region is the length of the element (separator in the separator section and filter/coalescer in that section) multiplied by the cross-sectional area of the region.

For the separator section, add the flows into the region from the segments to the total flow rate multiplied by the cross-sectional area of the region

divided by the sum of all region areas in the separator section. For the filter/coalescer region, add the flows into the region from the segments to the flow from the fraction of the area of each filter/coalescer that is in the region.

Divide the volume by the flow rates into the region to determine the residence time. The residence time for Figure 7 is given in Table 8.

Finally, the residence time in the region between the filter/coalescers and separators is equal to the cross-sectional area of the vessel multiplied by the distance between separators and filter/coalescers divided by the total flow rate for the vessel.

Table 8 - Residence times for the separator and filter/coalescer section

Filter/Coalescers			Separators		
Segment	Area (Sq. in.)	Residence Time (sec.)	Segment	Area (Sq. in.)	Residence Time (sec.)
wBFw	18,3384	1,663	wBAw	49,6760	1,0330
wFEw	18,3384	1,725	wCBw	49,6760	1,0330
wEDw	18,3384	1,663	wADw	30,1450	0,7980
wDCw	18,3384	1,725	wDCw	30,1450	0,7980
wCBw	18,3384	1,725	CDBC	5,3941	0,2620
BAFB	4,4380	0,807	DABD	5,3941	0,2620
FAEF	4,4380	0,807			
ADEA	4,4380	0,807			
BCAB	4,4380	0,807			
ACDA	4,4380	0,807			