

## LIMCA COMPARISON OF A BED FILTER AND A TWO STAGE CERAMIC FOAM FILTER

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### Abstract

The filtration performance of a bed filter and a two stage ceramic foam filter were compared based on LiMCA inclusion measurements. The bed filter uses a packed bed of alumina mesh and balls to remove inclusions. The two stage filter uses two ceramic foam filter plates; a coarser pore filter is fitted directly over a finer pore filter with a small gap between the two plates. The objective is to use the coarser filter to remove large inclusions so the finer filter can remove more and smaller inclusions without plugging. The main advantage of the two stage filter is to avoid downtime and recovery loss from having to flush the bed filter for alloy changes and from having to change out spent beds. LiMCA data was obtained with the bed filter for nine casts and with the two stage filter for five casts. Casts with the two stage filter included three ppi combinations and two filter factors.

### Introduction

Bed filters, packed beds of granular ceramic media, have been used since the 1940's to remove inclusions from molten aluminum alloys. A bed filter is used for multiple casts and is replaced when the metallostatic head across the filter reaches a limiting point. The large volume typical of a bed filter limits its flexibility for alloy changes – large flush casts are required. Bed filters provide very high inclusion removal efficiencies (>90%), and are often used in casting inclusion-sensitive products (1).

In the 1970's, ceramic foam filters (CFF) came into use. These filters are produced by impregnating polymeric foam with ceramic slurry, then firing the ceramic and burning away the foam. Ceramic foam filters are almost always in the form of flat plates and are normally used for one cast only. They provide more flexibility for alloy changes and are less costly than bed filters. Inclusion removal efficiency (25 to 75%) is considerably lower than for a bed filter (1).

In 1996, Selee Corporation introduced a dual stage filtration system (2). In this system, two ceramic foam filters are placed in a single filter bowl with a small (one inch) gap between the filters. Metal flows from top to bottom through both filters. The top filter is relatively coarse and acts to pre-treat the metal before it encounters the finer bottom filter. In this way, a finer pore filter with higher inclusion removal efficiency can be used without becoming plugged by retained inclusions.

### Experimental Apparatus and Procedure

This study was intended to determine whether a dual stage ceramic foam filter could provide metal quality equivalent to the A94 bed filter used in the ingot plant of Alcoa Waunarlwydd Works in Swansea, Wales. Testing was done on alloy 5182 using a tilting holding furnace and an Alcoa A622 degasser upstream of the filter.

The two stage ceramic foam filter used a 23" x 23" filter on top and a 20" x 20" filter on the bottom. Because of the high metal flow rate at the Swansea plant, two CFF bowls were used in parallel. This arrangement is shown in Figure 1. During the trial, some casts used both bowls while others used only one bowl. The filter factors using 1 and 2 bowls were 28 and 14 kg/sec/m<sup>2</sup> (2.4 and 1.2 lb/min/in<sup>2</sup>), respectively.

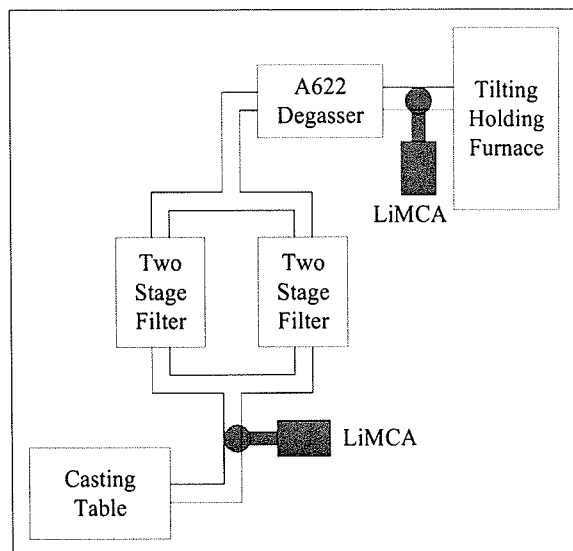


Figure 1: Layout of Swansea casting pit with two stage filters.

Inclusion concentrations were measured by LiMCA (3), a method based on the Coulter counter principle. Metal is cycled in and out of a glass probe through a 300 µm orifice. Non-metallic inclusions passing through the orifice produce a perturbation in the voltage between electrodes situated inside and outside of the glass probe. The inclusion size range covered by LiMCA is nominally 20 to 320 µm, although the maximum size that can be resolved is 140 µm.

One LiMCA unit was positioned between the holding furnace and the degasser, while the other unit was located downstream of the filter. The diagram of the casting pit in Figure 1 illustrates the locations of the LiMCA units. Measurements taken between the holding furnace and the degasser are identified as "Taphole" measurements, while those taken between the filter and the casting table are identified as "After Filter" measurements. Regular LiMCA probes were used for all of the measurements because acceptable voltage baselines were obtained without extension probes; there did not appear to be any interference from microbubbles or molten salt inclusions. This is in contrast to recent reports that showed interference from microbubbles when measurements were made downstream from a degasser (4, 5).

Statistical analyses of the cast average LiMCA values were made using "JMP" software (SAS Institute, Cary, North Carolina). An alpha value of 0.05 was used in these analyses, meaning that the probability that the averages are different needs to be 0.95 or greater before a difference is considered statistically significant.

#### LiMCA Inclusion Concentrations

Inclusion concentrations were measured at the taphole for eleven of the fourteen casts. Although there was considerable variation in the taphole LiMCA values, there was no statistically significant difference between taphole values for casts made with the bed filter and those made with the two stage CFF. These statistical comparisons are shown in Table I and Figure 2 for R20, R30, R40, R50, and R100. The LiMCA values have been normalized by setting the highest cast-average N20 value equal to 100 and multiplying all other inclusion concentrations by the ratio [100/maximum taphole N20]. R20, R30, R40, R50, and R100 represent the relative concentrations of particles larger than 20, 30, 40, 50, and 100 µm, respectively.

Table I: Statistical Comparison of Taphole LiMCA Values

Inclusion Size Range	Mean Inclusion Concentration		Probability of Difference
	Bed Filter Casts	Two Stage CFF Casts	
R20	59.9	51.3	0.424
R30	12.2	12.0	0.054
R40	3.4	4.3	0.452
R50	1.2	1.8	0.678
R100	0.037	0.033	0.136

In Figure 2, the diamond for each condition indicates the average value by the line across its center and the 95% confidence level by its height. The horizontal lines near the top and bottom of each diamond indicate the 95% confidence intervals for comparisons between the groups – if these lines overlap for the two groups, then the groups are not significantly different at 95% confidence. The fact that there was no statistical difference in taphole inclusion levels between the two conditions (bed filter and CFF) means that varying taphole inclusion levels will not bias the downstream comparisons between the two conditions.

Table II gives a summary of the average LiMCA values measured after the filter for each cast during the campaign. The ppi ratings of the ceramic foam filters used in the two stage filter are indicated as xx/yy where xx is the value for the coarser top filter and yy is for the finer bottom filter. The LiMCA values reported here have also been normalized by setting the highest cast-average N20 value equal to 100 and multiplying all other inclusion concentrations by the ratio [100/maximum after filter N20]. No particles larger than 100 µm were detected in

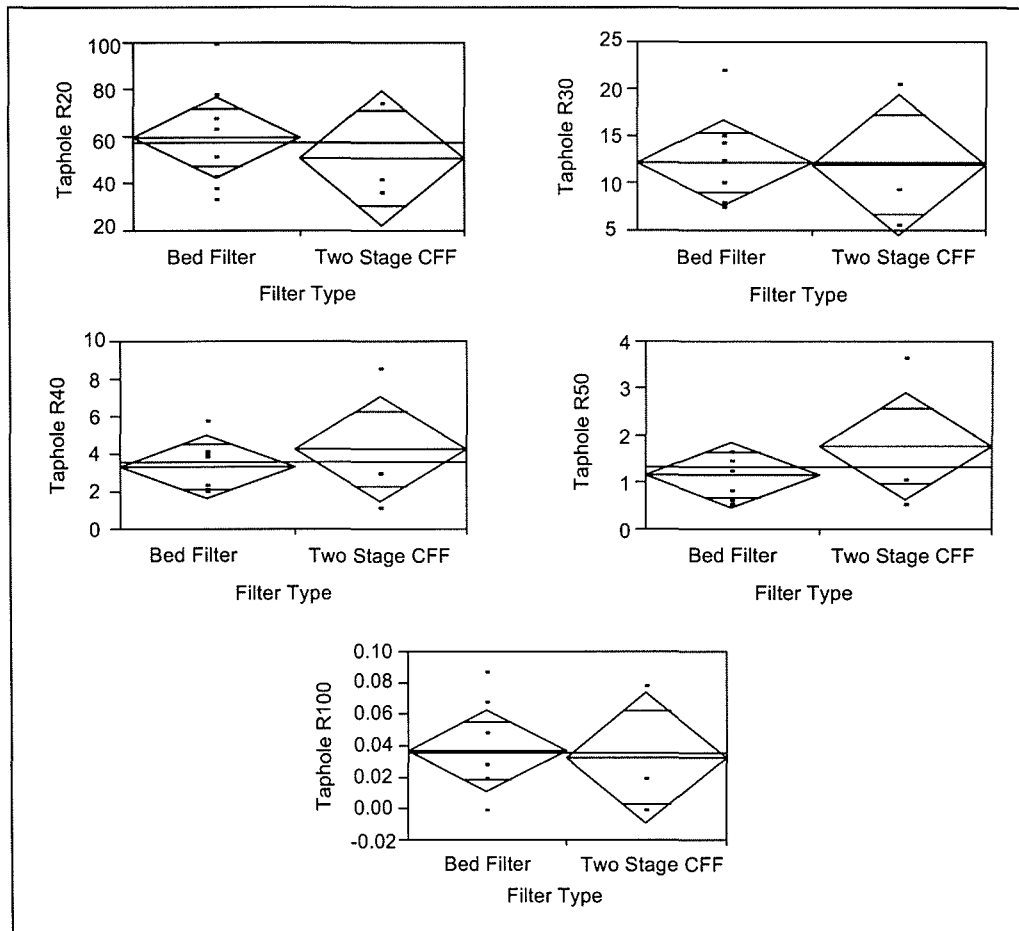


Figure 2: Statistical comparison of taphole LiMCA values for bed filter and two stage CFF.

Table II: Inclusion Concentrations Measured After Filter

Cast No.	Filter	ppi	Number of Bowls	After Filter Inclusion Concentrations				
				R20	R30	R40	R50	R100
1	Bed Filter			1.7	0.42	0.050	0.017	0
2	Bed Filter			1.3	0.27	0.13	0.067	0
3	Two Stage CFF	30/60	2	88.5	11.2	1.5	0.23	0
4	Two Stage CFF	50/70	2	3.8	0.37	0.12	0.050	0
5	Two Stage CFF	40/60	1	100.0	19.3	4.5	1.4	0
6	Two Stage CFF	50/70	1	27.6	7.3	2.1	0.55	0
7	Two Stage CFF	50/70	2	13.7	2.1	0.32	0.084	0
8	Bed Filter			5.0	0.18	0.017	0.017	0
9	Bed Filter			2.7	0.44	0.050	0.017	0
10	Bed Filter			1.8	0.18	0.084	0.084	0
11	Bed Filter			1.5	0.39	0.18	0.017	0
12	Bed Filter			2.7	0.87	0.32	0.15	0
13	Bed Filter			3.8	0.92	0.27	0.050	0
14	Bed Filter			3.4	1.2	0.47	0.39	0

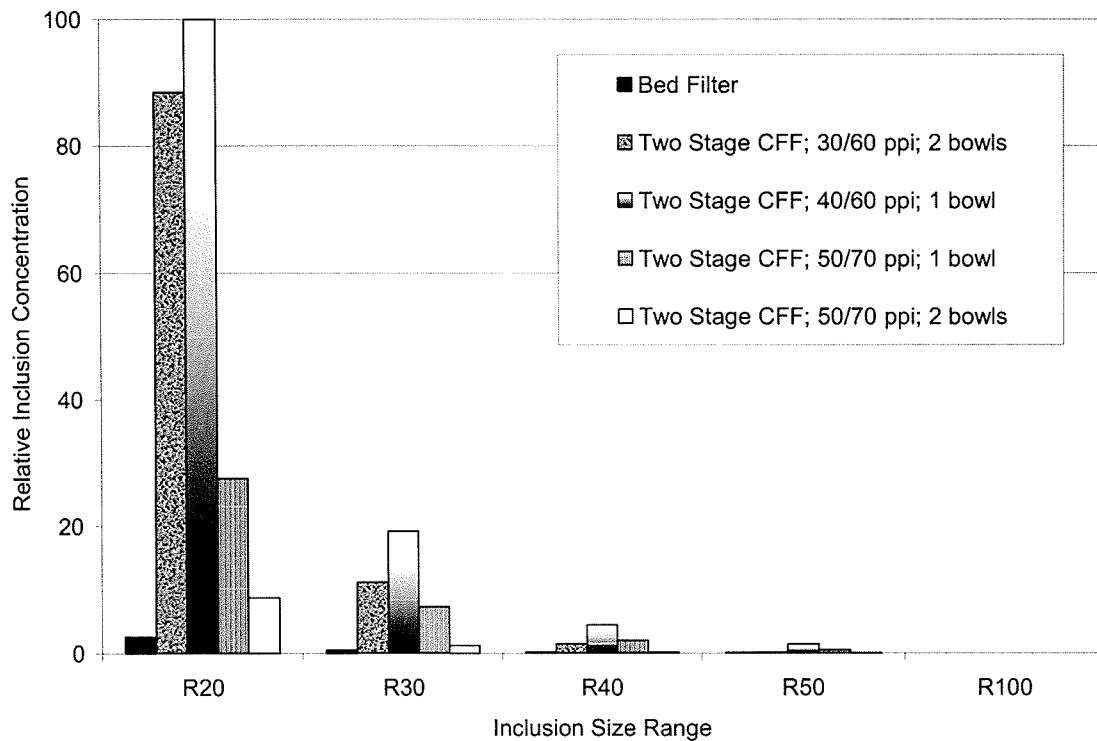


Figure 3: Average inclusion concentrations after filter for each filter type.

any of the LiMCA samples after any of the filters, even though there were particles in this size range detected at the taphole for nine of the casts.

#### Comparison of Filter Types

The overall average LiMCA values measured after the filter for each type of filter are shown in Figure 3. Bed filter data is an average of nine casts, while data from the two stage CFF with 50/70 ppi filters and two bowls represent an average of two casts.

Since only one cast was made for most of the two stage filter combinations, not many statistical comparisons can be made. However, some reasonable trends in the data seem apparent. First, the lowest inclusion concentrations with the two stage filter were obtained with two bowls using 50/70 ppi filters in the top and bottom stages, respectively. It seems reasonable that the finest pore size combination and the largest filter area gave the best results.

Second, both the filter area and the pore size had an impact on metal cleanliness, with pore size appearing to be more important. Although the cast with 50/70 ppi filters in a single bowl had higher inclusion concentrations than the casts with the same filters in two bowls, it had lower inclusion concentrations than 30/60 ppi filters with two bowls. The highest inclusion concentrations occurred with 40/60 ppi filters in a single bowl.

Since two casts were made with the best conditions for the two stage filter (two bowls with 50/70 ppi filters), a statistical comparison was made between this combination and the A94 bed filter.

Table III and Figure 4 give the results of this analysis. For R20 concentrations, there was a statistically significant difference (Probability of Difference > 0.95); the average with the two stage filter was three times higher than with the bed filter. For R30, although the difference was not statistically significant, the average with the two stage filter was twice that obtained with the bed filter. For inclusion size ranges of R40 and R50, there were no statistically significant differences, and for R100 there was no difference as no inclusions larger than 100  $\mu\text{m}$  were detected with either filter.

Table III: Statistical Comparison of After Filter LiMCA Values

Inclusion Size Range	Mean Inclusion Concentration		Probability of Difference
	Bed Filter	Two Stage CFF; 50/70 ppi; 2 bowls	
R20	2.66	8.75	0.985
R30	0.54	1.24	0.869
R40	0.18	0.22	0.292
R50	0.09	0.07	0.196
R100	0.00	0.00	0.000

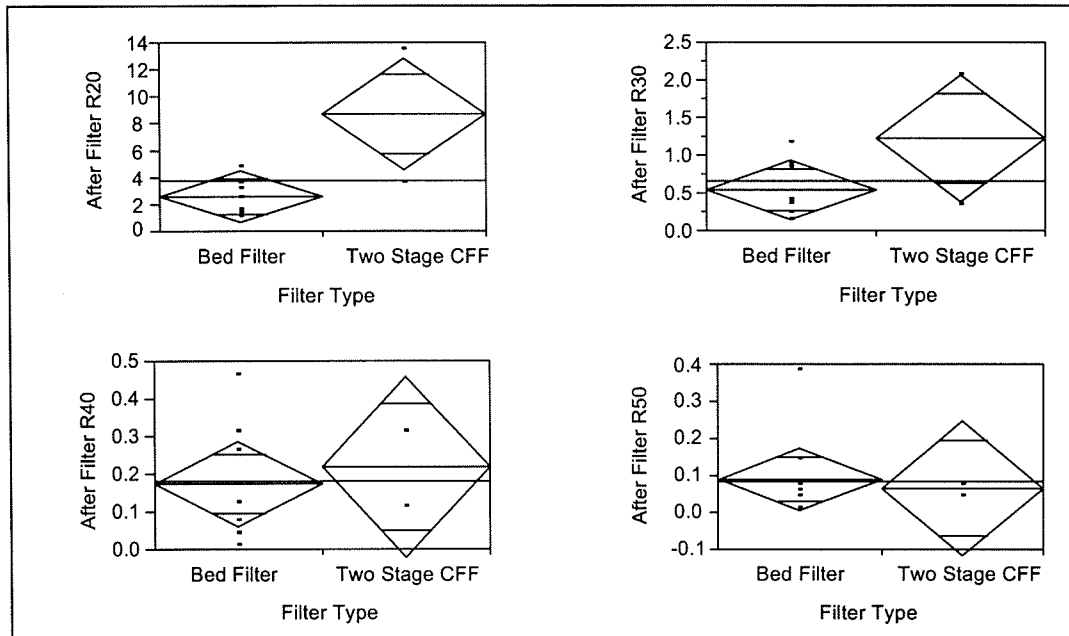


Figure 4: Statistical comparison of after filter LiMCA values for bed filter and two stage CFF with 50/70 ppi filters and two bowls.

In summary, the two stage filter was not as effective as the bed filter at removing small inclusions, 20 to 40  $\mu\text{m}$ , but for inclusions larger than 40  $\mu\text{m}$  it appears to be just as effective as the bed filter.

Because no particles larger than 100  $\mu\text{m}$  were detected in any of the tests, it is very possible that the performance of the metal for some products would be identical regardless of the conditions used in the two stage filter. However, because the volume of metal sampled by LiMCA is very small compared to the volume of metal cast and the occurrence of these large inclusions is rare, one should be cautious about conclusions made for this size range.

#### Filtration Efficiency

Filtration efficiencies achieved with the combination of the degasser and the filter were determined for those casts where LiMCA measurements were taken both at the taphole of the furnace and after the filter. These efficiencies are summarized in Table IV and illustrated in Figure 5. No statistical comparisons could be made with this data because all of the two stage filter results represent only one cast at each condition.

For R20 inclusions, none of the two stage filter configurations were as efficient as the bed filter. For R30, the efficiency of the two stage filter with 50/70 ppi filters and two bowls was very close to that of the bed filter, while for R40 and R50 the efficiency of this configuration was slightly higher than the bed filter. For R100 inclusion concentrations there were no differences between any of the filters; all were 100% efficient.

The two trials with single bowls show considerably lower filtration efficiencies. The cast with 40/60 ppi filters in a single bowl had negative filtration efficiency for R20 and R30. The higher concentrations of 20 to 40  $\mu\text{m}$  particles after the filter, which are seen as an increase in R20 and R30, are probably due to the addition of chlorine in the degasser. Molten salt droplets can be formed in the degasser and can be large enough to be measured by LiMCA.

The two stage ceramic foam filter actually performs quite well considering the relative sizes of the two types of filters. Table V summarizes the R20 removal efficiencies and the filter factors for the bed filter and the two stage CFF with 50/70 ppi filters. The area of the bed filter is much larger than the area of the CFF, so the filter factor through the bed is considerably lower.

#### Conclusions

1. The lowest inclusion concentrations obtained with the two stage filter were obtained when two bowls were used in parallel with 50/70 ppi filters in each bowl.
2. Two bowls used in parallel (filter factor = 1.2 lb/min/in<sup>2</sup>) gave lower inclusion concentrations than using one bowl (filter factor = 2.4 lb/min/in<sup>2</sup>).
3. No inclusions larger than 100  $\mu\text{m}$  were detected with the bed filter or with any combination used in the two stage filter.
4. For R20 inclusions the bed filter gave significantly fewer inclusions than the two stage filter with two bowls and 50/70

Table IV: Filtration Efficiency

Cast No.	Filter	ppi	Number of Bowls	Filtration Efficiency (%)				
				R20	R30	R40	R50	R100
1	Bed Filter			97.7	97.0	98.8	99.2	100
5	Two Stage CFF	40/60	1	-38.4	-18.8	11.8	22.0	100
6	Two Stage CFF	50/70	1	55.9	24.0	2.4	44.1	100
7	Two Stage CFF	50/70	2	89.3	94.0	97.8	98.7	100
8	Bed Filter			96.2	99.3	99.8	99.4	100
9	Bed Filter			96.9	98.0	99.3	99.3	100
10	Bed Filter			97.0	98.6	97.8	92.5	100
11	Bed Filter			99.1	99.0	98.1	99.3	100
12	Bed Filter			97.5	96.5	95.3	93.0	100
13	Bed Filter			96.8	94.7	92.7	94.8	100
14	Bed Filter			94.8	90.7	87.7	74.4	100

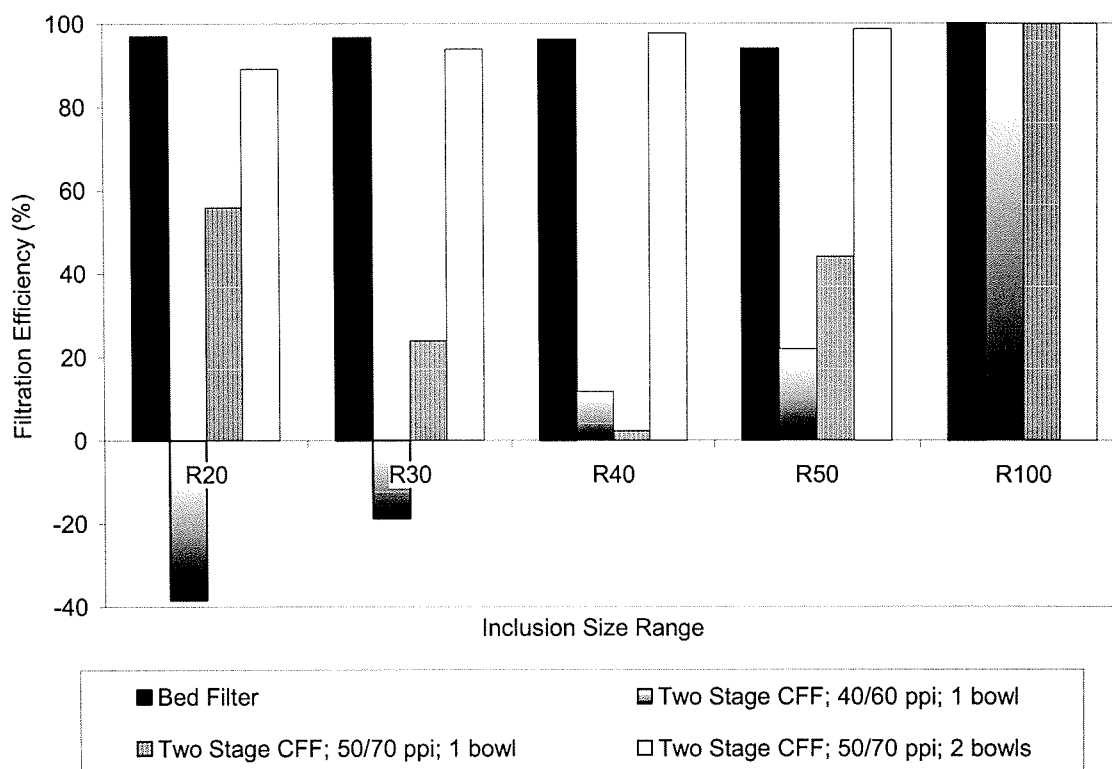


Figure 5: Average filtration efficiencies for each filter type.

Table V: Filtration Efficiency versus Filter Factor

Filter	Filter Factor (lb/min/in <sup>2</sup> )	R20 Filtration Efficiency (%)
Bed Filter	< 1	97
Two Stage CFF; 50/70 ppi; 2 bowls	1.2	89
Two Stage CFF; 50/70 ppi; 1 bowl	2.4	56

ppi filters. For R30, R40, R50, and R100 inclusions, there was no statistically significant difference between the bed filter and the two stage filter with two bowls and 50/70 ppi filters.

- The inclusion removal efficiency of the two stage filter with two bowls and 50/70 ppi filters was lower than that of the bed filter for R20 and R30, but was greater than or equal to the bed filter for R40, R50, and R100.

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#### References

- D. H. DeYoung, "Metal Filtration Performance: Removal of Molten Salt Inclusions," Sixth Australian Asian Pacific Conference on Aluminium Cast House Technology, ed. P. R. Whiteley and J. F. Grandfield (Warrendale, PA: The Minerals, Metals & Materials Society, 1999), pp. 121-131.
- L. S. Aubrey, M. A. Cummings, C. L. Oliver, and M. Chow, "The Development and Performance Evaluation of a Dual Stage Ceramic Foam Filtration System," Light Metals 1996, ed. W. Hale (Warrendale, PA: The Minerals, Metals & Materials Society, 1996), pp. 845-855.
- J.-P. Martin, R. Hachey, and F. Painchaud, "On-line Metal Cleanliness Determination in Molten Aluminium Alloys Using the LiMCA II Analyser," Light Metals 1994, ed. U. Mannweiler (Warrendale, PA: The Minerals, Metals & Materials Society, 1994), pp. 915-920.
- M. Cooksey, T. Ware, and M. J. Couper, "Effect of Pressure Cycle and Extension Probe on LiMCA Measurement of Inclusions," Light Metals 2001, ed. J. L. Anjier (Warrendale, PA: The Minerals, Metals & Materials Society, 2001), pp. 965-971.
- T. N. Ware, M. Cooksey, and M. J. Couper, "Measurement of the Performance of In-Line Processes Using LiMCA," 7th Australian Asian Pacific Conference on Aluminium Cast House Technology, ed. P. R. Whiteley (Warrendale, PA: The Minerals, Metals & Materials Society, 2001), pp. 45-54.