Project acronym: HEATSTACK

Project full title: Production Ready Heat Exchangers and Fuel Cell Stacks for Fuel Cell mCHP

Grant agreement no: 700564

D5.1 Build of 160 CAPHs using prototype process

Version: 1.1

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

Version History

Version	Date	Author	Organisation	Description
V1.0	09/05/17	C Penny	SFC	First Draft
V1.0	10/05/17	R Subramanyam	SFC	Content Review
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V1.1	02/07/17	J Hughes	PNO	Addition of 3 statements, FCH logo and EC flag on this page.

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1 Glossary

1.1 Terminology

Acronyms and abbreviations

Table 1: Acronyms and abbreviations with their full descriptions

SFC	Senior Flexonics (UK)
SFO	Senior Flexonics Olomouc (Czech Republic)
PNO	PNO Consultants Ltd (UK)
VAILLANT	VAILLANT GmbH (Germany)
SUNFIRE	SUNFIRE GmbH (Germany)
ICI	ICI Caldaie S.p.A (Italy)
UBHAM	University of Birmingham
mCHP	micro-Combined Heat and Power
CHP	Combined Heat and Power
SOFC	Solid Oxide Fuel Cell
CAPH	Cathode Air PreHeater
PACE	Pathway to a Competitive European FC mCHP market

2 Deliverable D5.1

2.1 Statement of Deliverable

Build of 160 CAPHs using prototype processes.

3 Introduction

3.1 Aims of Deliverable

The aims of the deliverable when the Grant Agreement was signed was to build 160 Cathode Air Pre Heaters. These coolers were to a design that Senior Flexonics, Crumlin had built prior to the start of HEATSTACK and that Vaillant had built into units and tested without any concerns raised or encountered. Some of the units would be defined as hybrid, having the core of a G6 but the interfaces of G5 to fit Vaillant's test rigs.

Most of the units were to be built into mCHP units at Vaillant and be put into the field for long-term trials as part of the PACE FCH-02.9-2015. Feedback from both the prototype build process, captured in D5.3 CAPH build report, and field trials captured in D5.4 Report on test results of AluChrom 318 components in a range of units and D5.5 Report on outcomes of testing pertaining to the CAPH would allow any design changes necessary for G7 full production to be made.

4 Changes to Deliverable

4.1 Initial highlighting of a concern with G6 design by Vaillant

As there was a high work load required to deliver 160 CAPHs by May 2017 ordering of material and manufacture was started as soon as HEATSTACK commenced.

At the GA meeting held at Remscheid on 19th and 20th April 2016 Vaillant showed a G6 CAPH that had suffered significant distortion. The unit was returned to SFC where a report SFFR 1771 was completed and sent to Vaillant. (Appendix 1). An email from Jens Funcke, Vaillant was received 2nd May 2016 stating a second G6 CAPH had severe distortion. (Appendix 2) this CAPH was returned from Vaillant and report SFFR 1773 issued 10th June 2016.

A conference call with Vaillant and VDM (the AluChrom material supplier) was made on 12th May 2016 were it was agreed that the heat distribution across the gas plate was likely to be to root cause of the distortion. Deliverable D2.3 records the design changes that were made to the gas plate to alleviate the distortion. At this point work on the 160 CAPHs was significantly reduced. A new gas plate forming tool was manufactured and further G6 units built for Vaillant sign off testing.

At the GA meeting held in Verona on 27th and 28th September 2016 Vaillant and SFC had detailed discussions on the results of a Vaillant thermal cycle test that had been carried out on a hybrid G6.1 design with the new plate design. Although the distortion was significantly less the weld joints to the end cap had failed. This is again reported in deliverable D2.3.

SFC went through a further design iteration to resolve this weld failure. This included more changes to the tooling to accommodate the design change.

Further CAPHs were built to this new design level and supplied to Vaillant for testing.

On 27th February 2017 SFC received an email from Vaillant confirming that the CAPH had successfully passed the thermal cycle test. This is again reported in deliverable D2.3. At this point SFC were ready to start manufacturing CAPHs in volume again and ordered some further material and changes to the tooling to enable the new design to be manufactured.

On 7th March 2017 SFC, as the HEATSTACK coordinator, received the letter of termination from Vaillant. (Appendix 3). At this point all work by SFC stopped on D5.1.

A new set of deliverables will be submitted to the FCH-JU to replace at least some of work package 5.

5 Communications with FCH-JU and Vaillant

5.1 Email exchanges between FCH-JU and SFC, Vaillant and SFC

In late April 2016 emails were exchanged with Vaillant discussing the first deformation failure. At this point the level of concern was not high and no root cause had been established. (Appendix 4)

A meeting was held at VDM 12th May 2016 and from that meeting a presentation was generated by Vaillant on the suspected root cause of the deformation. (Appendix 5)

SFC then completed an intense period of plate redesign and CFD to address the potential root cause. This is captured in the deliverable D2.3.

On 22nd September 2016 SFC received a letter from Vaillant stating that Vaillant would halt development of the G7 design level and focus on overcoming the obstacles on G6. The letter stated that Vaillant were fully committed to finish the development of the G6 and prepare for market launch in 2017 (Appendix 6)

On 27th February 2017 an email was received from Vaillant confirming that the new plate design had completed the thermal cycle test and had passed. This is captured in the deliverable D2.3

Throughout this development process with Vaillant SFC kept FCH-JU fully informed. On 19th August 2016 SFD sent an email (Appendix 7) informing of the first concerns.

A further email and reply from FCH-JU (Appendices 8 and 9) were sent and received on 21st November 2016.

6 CAPHs built

6.1 Original G6 design

No parts to this level were despatched to Vaillant during HEATSTACK. However, many subassemblies were built.

6.2 New plate G6.1 design

Three CAPHs, one built to fit a G6 system and two built as hybrids to fit G5 test bench. (Appendix 10)

6.3 New plate, Crofer end plates and weld ribs G6.2 design

Eleven CAPH’s were built to the latest G6.2 design.

7 Material orders

7.1 For original G6 design

From 1st April 2016 raw material and components were ordered to build 160 CAPHs for D5.1 plus 25 CAPHs as part of WP2. As a significant amount of new tooling and processes were being developed that would generate high levels of scrap an over order was placed.

Appendix 12 lists the material purchased for G6.

7.2 For G6.1 design

As stated above SFC redesigned both the gas plate and the weld joints. High cost components were ordered for the initial trial parts to the G6.1 design. Once a level of confidence had been achieved, and in the expectation that Vaillant would be pushing hard for delivery of more CAPHs once testing was completed addition raw material was ordered.

Appendix 12 lists the material purchased for G6.1 and 6.2

8 Scrap of components due to design changes

8.1 Scrap due to plate design change

Current stock within the HEATSTACK project
1035 Plates
695 Welded cells
15 Welded stacks.

This material would have been enough to build 116 CAPHs (disregarding scrap).

Figure 1

8.2 Scrap due to addition of weld ribs, material change of end caps and new position

Drawing Number	Issue	Part Description	Qty/Unit	Supplier	Piece Price	On Order	Stores Stock	Issued	Order Required (195 Assy)	PO	Due Date	Re-DESIGN SCRAPPED
3015-100-1616	B	LONG INTERFACE COLLAR - 10mm	1	Safelok	2.55		175	20	0	0017600054		584
3015-100-1617	B	SHORT INTERFACE COLLAR - 3mm	3	Safelok	2.19		525	60	0	0017600054		1164
3015-100-1620	B	GAS IN PIPE	1	Safelok	4.24		195		0	0017600054		569
3015-100-1270	A	BLANKING PLATE (Disc)	2	SubCon	0.29		1918	82	-1610	C057589		0

This material was scrapped due to design change for the repositioning of the end plates and adding weld ribs. These parts were sufficient for 175 CAPHs.

Table 1

9 Tooling orders

9.1 For original G6 design

From 1st April 2016 work started on ordering capital and tooling for the manufacture of the 160 CAPHs. A formal specification for TECsystems (upgrade of production laser weld machine) was generated and after discussions and review and order placed on 19th May 2016. For other capital equipment and tooling formal meetings were held with Brecon Designs and MacGregor to define and agree the specifications. First orders were placed 26th May 2016 and the last order (before design changes) 10th August 2016. All tooling and capital for prototype build was delivered prior to Vaillant's letter of termination. Deliverables D2.1 and D2.2 give a detailed breakdown of both the capital and the tooling.

9.2 For G6.1 design

An upgrade of the cell welding tool to suit the re-designed plate was placed on 7th July 2016. This was followed by orders to modify tooling to allow the new outer ribs and changed lengths to be accommodated, these were placed on 5th October 2016. All tooling and capital for prototype build was delivered prior to Vaillant's letter of termination.

Deliverables D2.1 and D2.2 give a detailed breakdown of both the capital and the tooling.

10 New processes/tooling/capital used in builds

10.1 Long cell wiping

On all previous builds the outer long cells had been welded at SFC and then sent out for the edges to be wiped over. This allowed the process and tooling to be improved by SFC and saved a wait of at least 3 days for wiped cells to be returned.

10.2 Welding of spacers

A small design change was made to the spacer to enable better location and alignment of the two halves. This improved the quality of the weld. The old tooling had poor location, could only weld two sets of spacers at a time and was manually clamped resulting in a reduced quality and a slow process. The new spacer tool used pneumatic clamping and welded multiple components.

10.3 Welding of cells

Due to the design change in the plate to reduce distortion the position of some of the weld paths had changed. This required new tooling inserts. The results of the welding with the new tool were very positive.

10.4 Welding of ribs to end plate and long cell

The original tack welding fixture was adapted to clamp the ribs to the long cells and end plate and laser weld. A double pass weld was used that gave excellent weld penetration.

10.5 Welding of sidewall to long cell

Previous to the manufacture of the G6.1 and 6.2 CAPHs within HEATSTACK all G6 CAPHs had been taken to a sub-supplier and the joints between the side walls and the wiped edges of the long cells had been manually welded. This process was costly, slow and didn’t give any learning or development.

The concern or risk with this joint has always been that the underside of the joint could not be supported. It is well know that unless the materials being welded are in intimate contact the laser weld will burn a hole rather than weld. All other laser welded joints on the CAPH are fully clamped.

The wipe on the long cell was changed from 90 degrees to 100 degrees. The intention was that the wiped face would be pushed down to 90 degrees when the side wall was clamped to it but give a reaction force ensuring the components were in close contact.

Results were very positive.

10.6 Welding of ribs to sidewall and end cap

The original tack welding fixture was adapted to clamp the ribs to the long cells and end plate and laser weld. A double pass weld was used that gave excellent weld penetration.

11 Appendices

11.1 Appendix 1 – SFFR 1771

senior Flexonics 04/05/16

Test Sample Examination

Date 4/5/16
Report SFFR1771
Engineer S.Fairhurst
Product Development Director C.Penny
Project Vaillant
Part Name CHP heat exchanger, pn 200-800-262.

Samples PO3613 no1, G6.1 heat exchanger with x14 Aluchrom 318 (0.3mm 3.5% Al) gas plates (pn 3015-100-1592 iss A) laser welded into stack.

Introduction

A sample was returned after customer system testing. The unit had been operated for 5500 hours with an average operating temperature of 900°C. Seven cold starts were carried out. Initial observations were of excessive distortion of the gas plates around the air in port. The sample was leak tested and then sectioned to allow the internal plates and joints to be examined.

Sample as returned – air in side

Sample air out side

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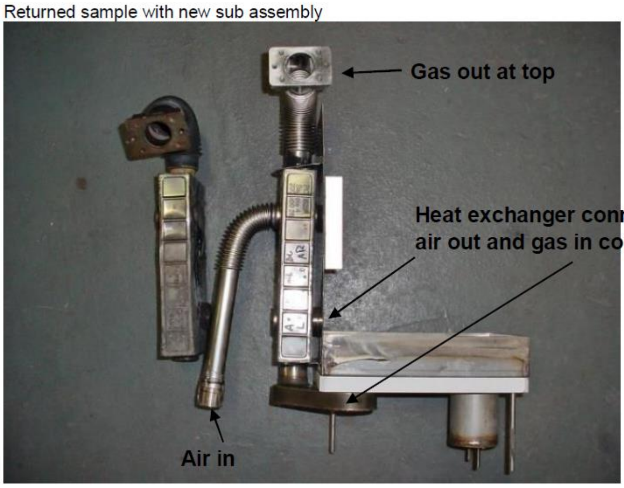
It was observed that there was distortion of the gas plates around the air in port, despite being at a lower temperature than the air out end, shown by the heat discolouration.

Distortion at air in port, blank side

Distortion at air in port, feed side

Returned sample with new sub assembly



Comparing the returned sample with a new sub assembly shows that the distortion around the air in port does not coincide with the rigid connections at the air out and gas in ports. Both the gas out and air in ports have corrugated tubes between the stack and the rest of the system. It was considered that the air in tube corrugations may not provide enough flexibility.

Leak test

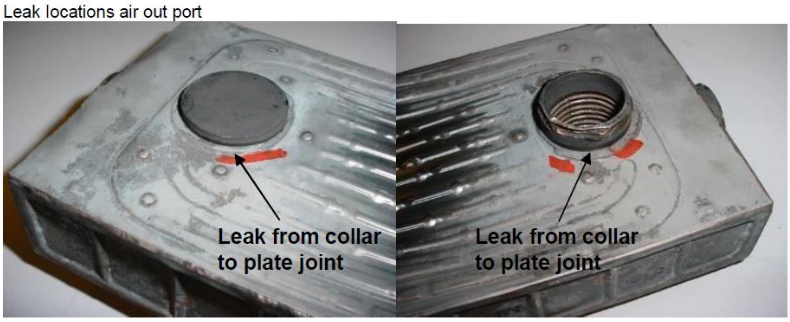
The sample was tested for both gas side and air side with 0.5bar air pressure while submerged in water. The gas side test revealed a leak at an outer gas plate to end cap weld, which appeared to have been damaged. Feedback from the customer suggested the split could have been caused when the sample was removed from the system. No leaks were observed from the air side.

Gas in end

The coolant side test revealed no internal leaks into the gas side. However, there were small leaks from the collars at the air out end which could allow heated air to leak into the atmosphere.

Leak test air side

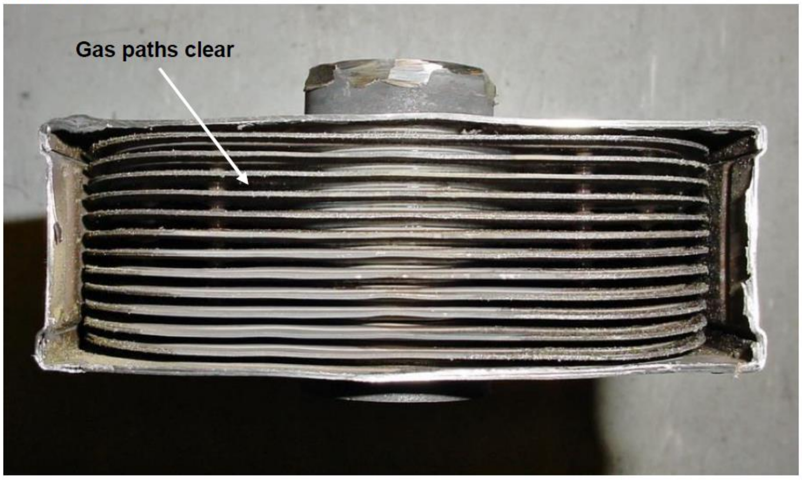
Leak locations air out port



Section and examination

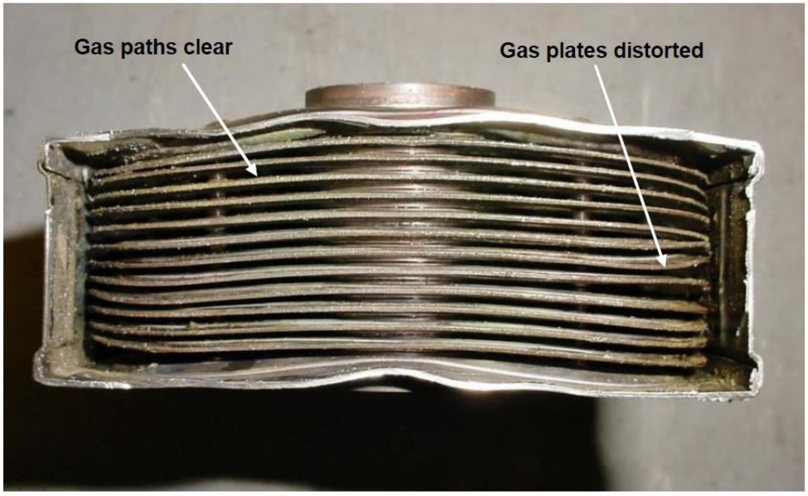
The end caps were removed to allow the inner gas plates to be examined (gas flow between plate cells).

Gas in end



Despite the high temperatures experienced, as evidenced by the heat discolouration, the gas plates had remarkably little distortion at the gas inlet end. There was no evidence of reduced gas path cross section between the plate cells.

Gas out end

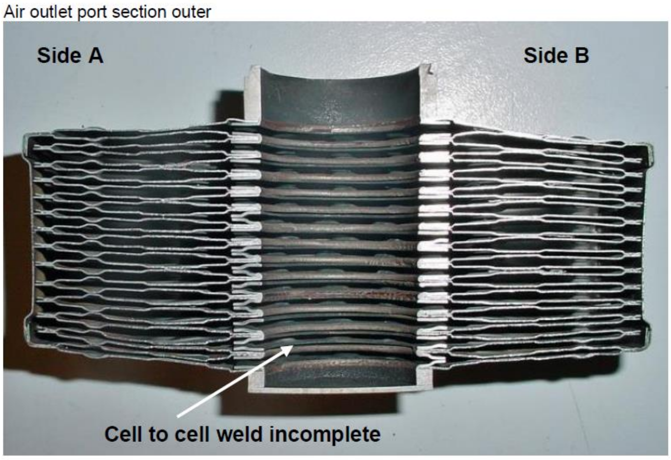


Although there was greater distortion at the gas outlet end, the gas pathways appeared clear around the air ports.

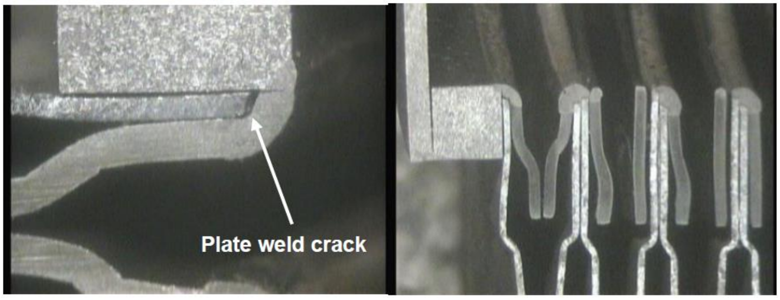
The stack was then sectioned across the air ports to allow the joints to be examined.

Air port sections

Air outlet port section outer

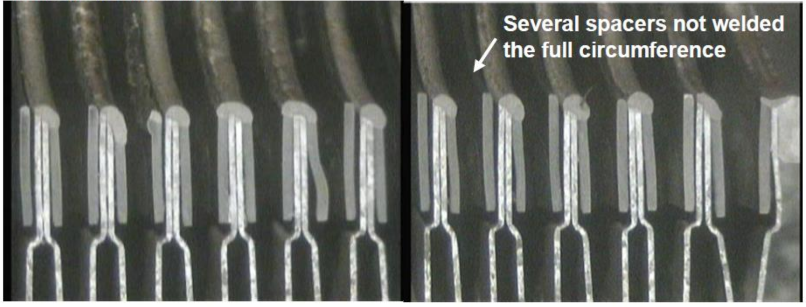


Microscope images of air outlet port welds
Blanked end collar weld side A



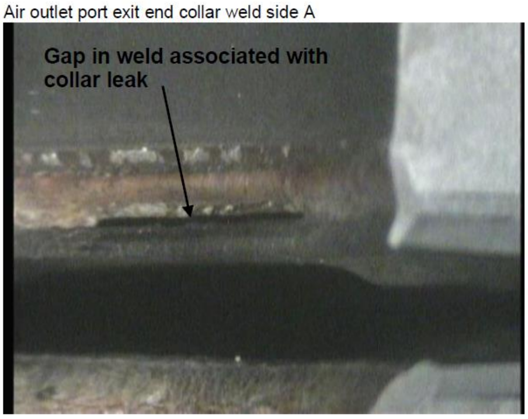
As leaks had been identified at the air outlet collars, the laser welds were closely examined. The gas plate to collar weld at the blanked end was found to be cracked.

Air out side A cell to cell joints



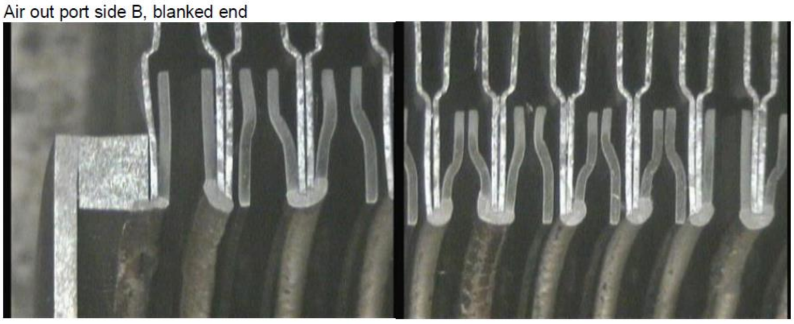
Although most of the cell to cell laser welds had not covered four layers at the section, all the welds covered all four layers at some portion of the joint circumference. This had prevented individual cells from expanding. None of the spacer halves had separated on the outer half.

Air outlet port exit end collar weld side A

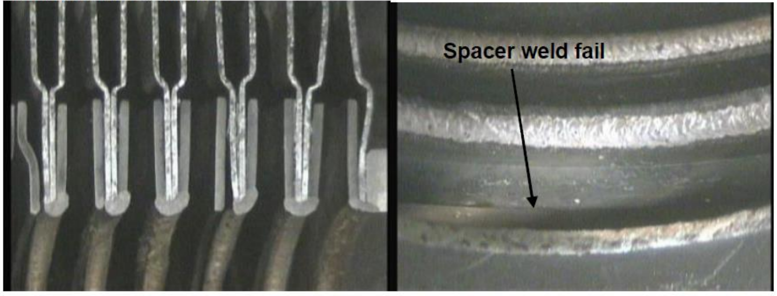


There were gaps in the collar weld (air exit end) which were thought to be source of the leak identified in the under water test.

Air out port side B, blanked end

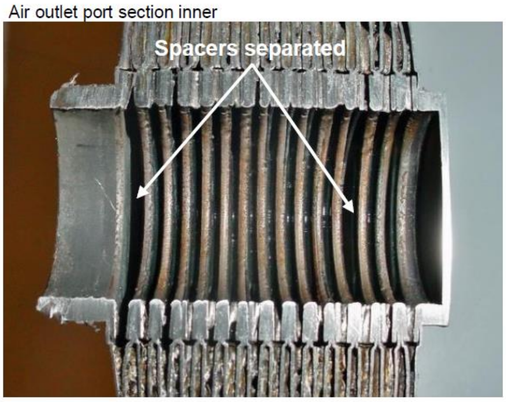


Air out port side B, exit end

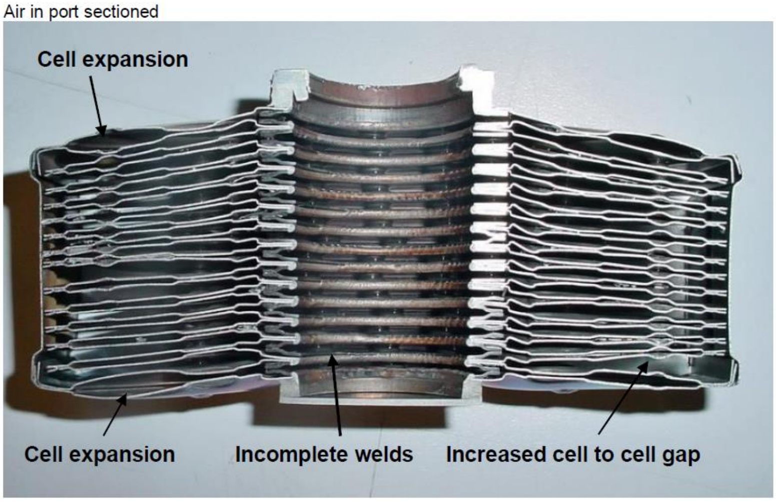


Two spacers had separated on the inner facing portion.

Air outlet port section inner



Air in port sectioned



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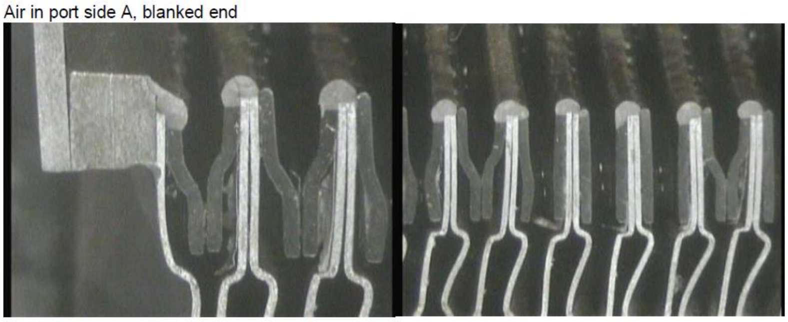
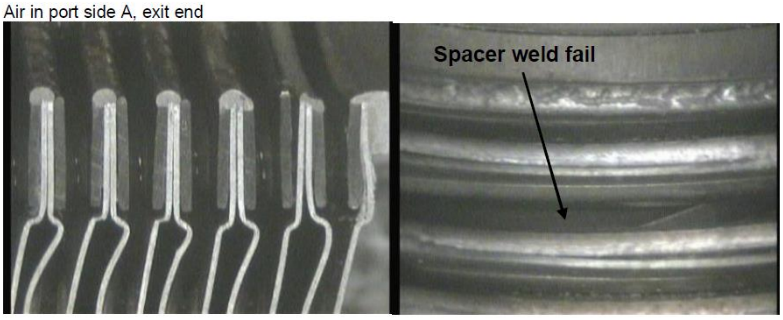
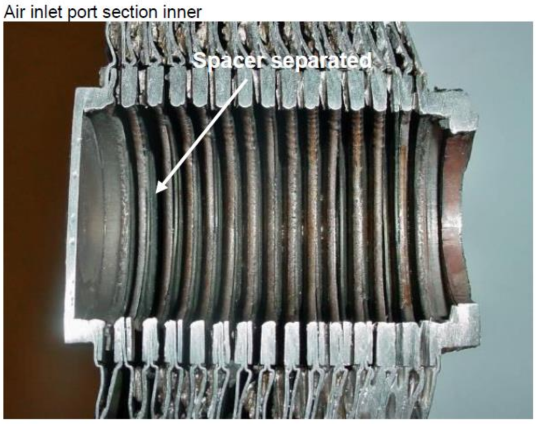
Air in port side A, blanked end



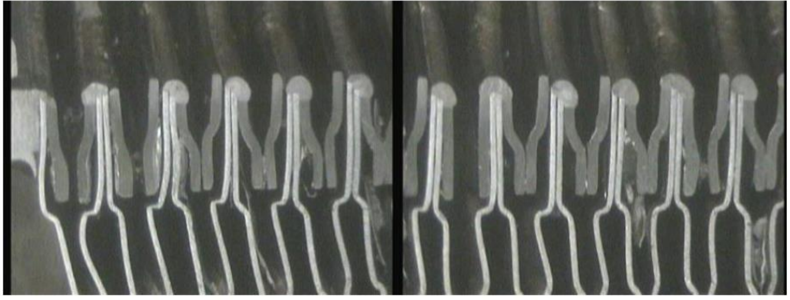
Air in port side A, exit end



Air inlet port section inner

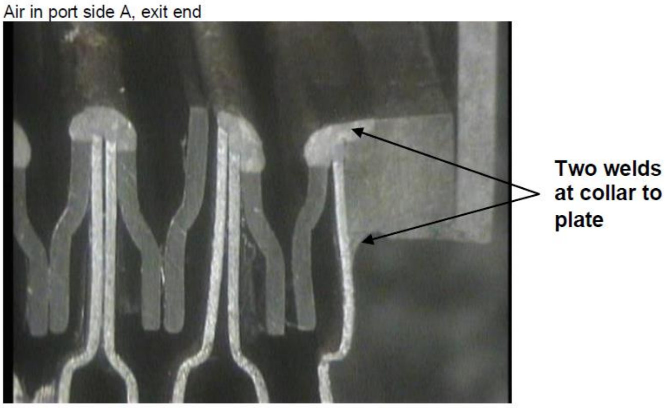


Air in port side B, blanked end



As with the outlet end, most of the cell to cell laser welds had not covered four layers at the section, though all the welds covered all four layers at some portion of the joint circumference. This had prevented individual cells from expanding. A spacer had separated on the inner facing portion.

Air in port side A, exit end

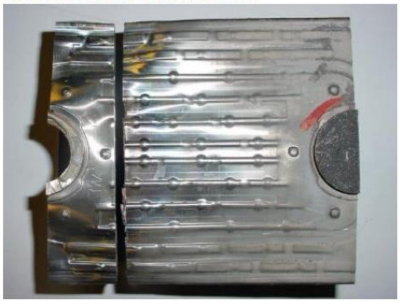


Two welds at collar to plate

It was noted that the air inlet port blanked end had two welds at the collar to gas plate, one around the ID and another around the OD. This would be expected to improve joint robustness.

As there appeared to be greater distortion adjacent to the air inlet port, another section was made.

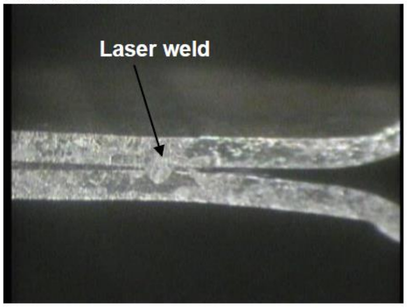
Stack sectioned across distortion



Section adjacent to air inlet port

Despite significant distortion, all the gas plates had intact laser welds at the four dividers sectioned, with air pathways maintained. The distortion had resulted in variable gaps between the gas plate cells, mainly increasing gaps. This would have affected gas flow, though as the gas inlet end had very little distortion, which should minimise the variation in gas flow distribution.

Divider laser weld section



Weld issues observed

1) There were leaks from the air outlet port collar to gas plate joints, both collars. At the air inlet, one of the collars had a second weld around the OD, which was a repair due to a leak.
2) Many of the cell to cell welds at the air ports were inconsistent, not covering all four layers (two gas plates and two spacers) for the full circumference.
3) Three of the spacers had failed welds at the long pads, likely affecting air flow distribution and allowed excess distortion.

The weld issues were considered to be a consequence of processing rather than insufficient robustness of the design.

Observations / Discussion

Although there was significant distortion of gas plates around the air inlet port, the gas paths had not been closed either side of the air port, showing that revisions to the plate design had successfully prevented gas paths being closed up.

The heat exchanger stack has rigid connections at the gas inlet and air outlet. Thermal growth is allowed by corrugated pipes at the gas outlet and air inlet. It was considered that the air inlet pipe may lack enough flexibility to compensate for the stack thermal growth without inducing significant stresses at the air inlet port. This could be a factor of the air inlet pipe corrugation's form and the lower temperature due to the air flow. An additional set of more flexible corrugations has been considered for a future revision of the air inlet pipe. For FEA analysis on the thermal growth see report in Job7403.

There was feedback from the customer that the gas temperature ramp up from ambient to 930C took 3 hours, with air flow started before the gas and air flow stopped after the gas. This would suggest that distortion was unlikely a result of an excessive temperature gradient during start up. A comment was made that whereas the start up burner was directly on the G5 CAPH gas inlet, on the G6 the start up burner is at the fuel cell stack inlet.

Conclusion

The returned heat exchanger sample was found to have significant distortion of the gas plates around the air inlet port, despite being at a lower temperature than the air outlet end, as indicated by the heat discolouration. A possible cause of the distortion was insufficient flexibility of the air inlet pipe for the thermal growth of the stack. Modifying the air pipe for increased flexibility of the pipe has been considered.

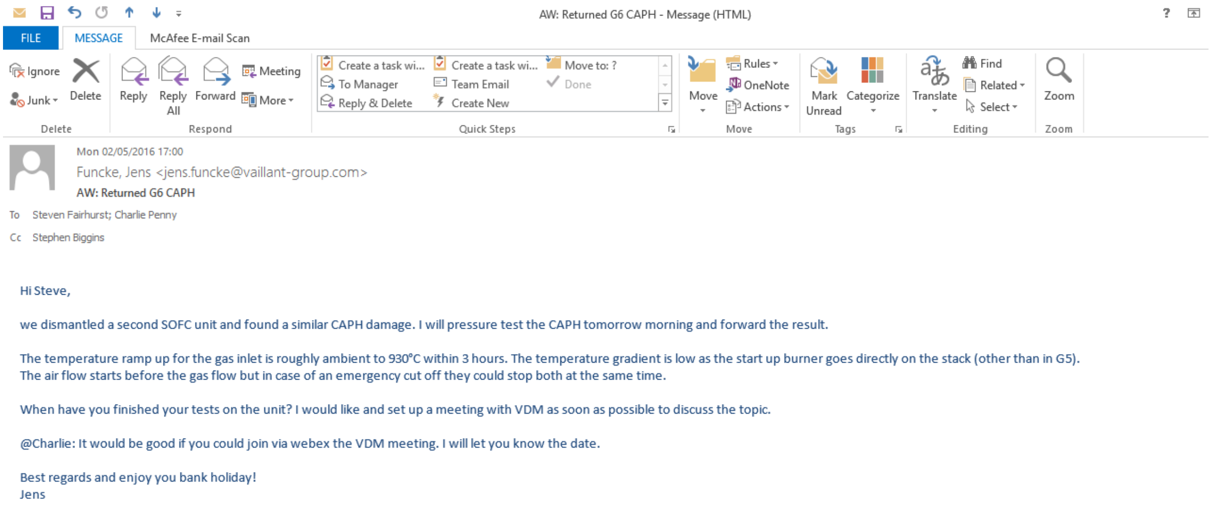
An outer gas plate to end cap weld was found to be damaged and leaking though this was attributed to the sample removal process.

No internal leaks across the air to gas sides were found in the underwater leak tests with 0.5bar air pressure applied.

Minor leaks were found at the air outlet collar to gas plate welds. The port side had a gap in the weld seam, suggesting that a very small leak could have increased during the test. However, the blanked collar weld was cracked at the outer gas plate. A potential solution would be to add a second weld around the outside of the collars, as observed on one of the inlet collars, if feasible for production.

Sectioning revealed that the majority of the cell to cell welds had not formed full 360 degree joints across both spacers. It was considered that this could allow some of the stack distortion observed. Additionally, three of the spacers were found to have pad weld failures though not the full circumference. Spacer weld checking has been improved for current prototype production.

11.2 Appendix 2 – Email from J Funke



Mon 02/05/2016 17:00

Funcke, Jens <jens.funcke@vaillant-group.com>

AW: Returned G6 CAPH

To Steven Fairhurst; Charlie Penny

Cc Stephen Biggins

Hi Steve,

we dismantled a second SOFC unit and found a similar CAPH damage. I will pressure test the CAPH tomorrow morning and forward the result.

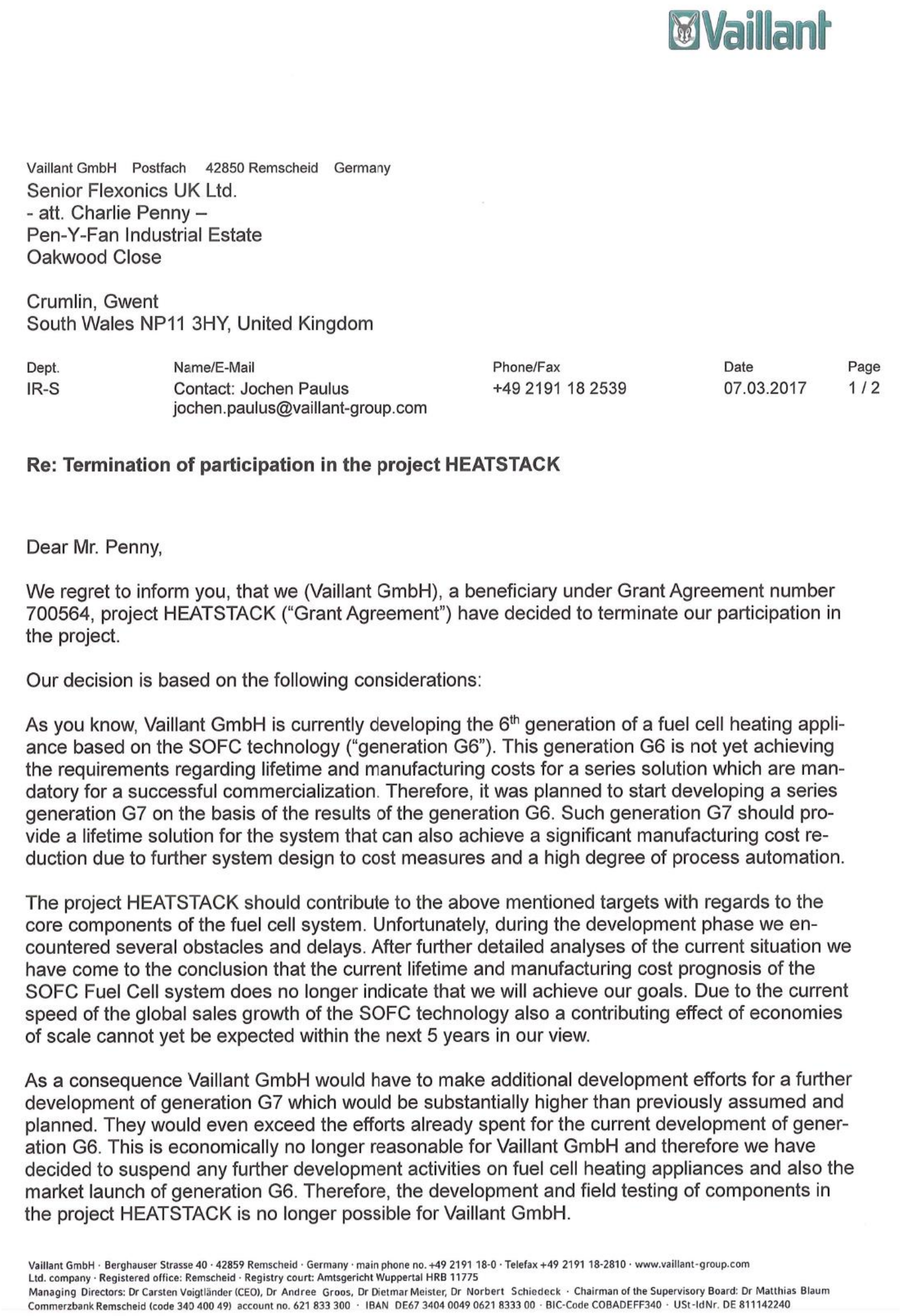
The temperature ramp up for the gas inlet is roughly ambient to 930°C within 3 hours. The temperature gradient is low as the start up burner goes directly on the stack (other than in G5). The air flow starts before the gas flow but in case of an emergency cut off they could stop both at the same time.

When have you finished your tests on the unit? I would like and set up a meeting with VDM as soon as possible to discuss the topic.

@Charlie: It would be good if you could join via webex the VDM meeting. I will let you know the date.

Best regards and enjoy you bank holiday!
Jens

11.3 Appendix 3 – Termination letter from Vaillant



Vaillant GmbH Postfach 42850 Remscheid Germany
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- att. Charlie Penny –
Pen-Y-Fan Industrial Estate
Oakwood Close

Crumlin, Gwent
South Wales NP11 3HY, United Kingdom

Dept.	Name/E-Mail	Phone/Fax	Date	Page
IR-S	Contact: Jochen Paulus jochen.paulus@vaillant-group.com	+49 2191 18 2539	07.03.2017	1 / 2

Re: Termination of participation in the project HEATSTACK

Dear Mr. Penny,

We regret to inform you, that we (Vaillant GmbH), a beneficiary under Grant Agreement number 700564, project HEATSTACK (“Grant Agreement”) have decided to terminate our participation in the project.

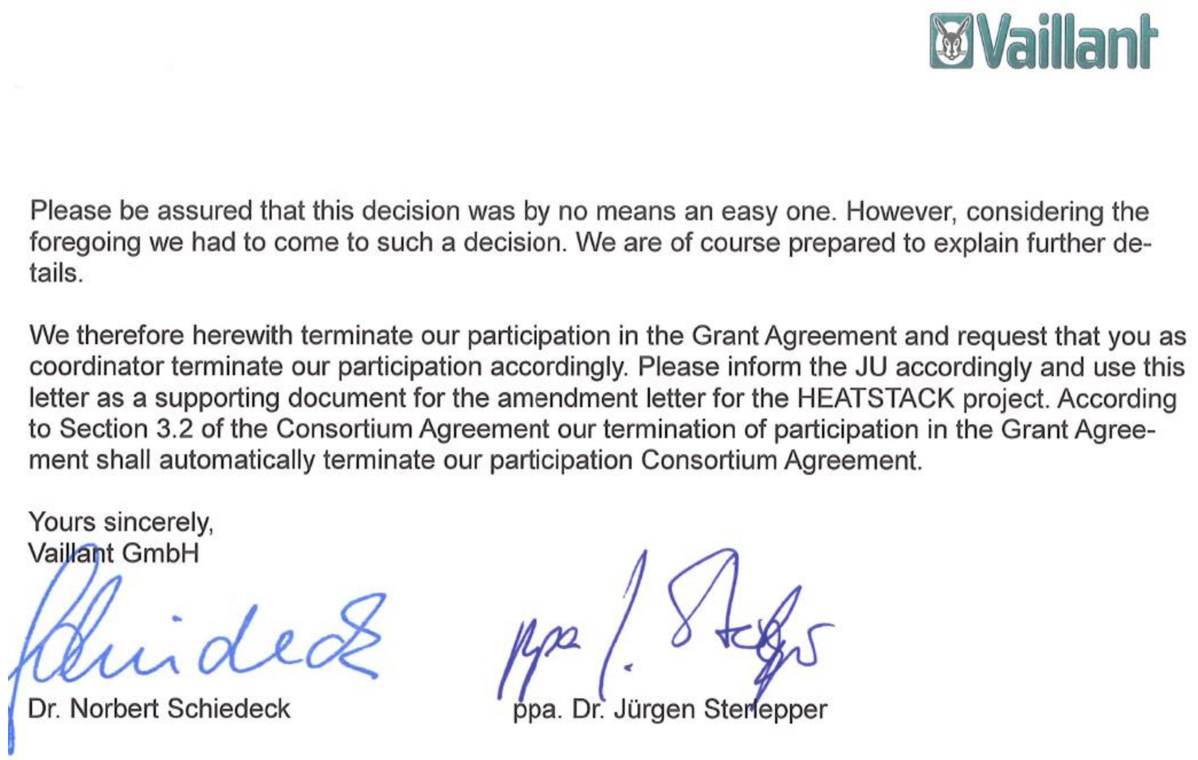
Our decision is based on the following considerations:

As you know, Vaillant GmbH is currently developing the 6th generation of a fuel cell heating appliance based on the SOFC technology (“generation G6”). This generation G6 is not yet achieving the requirements regarding lifetime and manufacturing costs for a series solution which are mandatory for a successful commercialization. Therefore, it was planned to start developing a series generation G7 on the basis of the results of the generation G6. Such generation G7 should provide a lifetime solution for the system that can also achieve a significant manufacturing cost reduction due to further system design to cost measures and a high degree of process automation.

The project HEATSTACK should contribute to the above mentioned targets with regards to the core components of the fuel cell system. Unfortunately, during the development phase we encountered several obstacles and delays. After further detailed analyses of the current situation we have come to the conclusion that the current lifetime and manufacturing cost prognosis of the SOFC Fuel Cell system does no longer indicate that we will achieve our goals. Due to the current speed of the global sales growth of the SOFC technology also a contributing effect of economies of scale cannot yet be expected within the next 5 years in our view.

As a consequence Vaillant GmbH would have to make additional development efforts for a further development of generation G7 which would be substantially higher than previously assumed and planned. They would even exceed the efforts already spent for the current development of generation G6. This is economically no longer reasonable for Vaillant GmbH and therefore we have decided to suspend any further development activities on fuel cell heating appliances and also the market launch of generation G6. Therefore, the development and field testing of components in the project HEATSTACK is no longer possible for Vaillant GmbH.

Vaillant GmbH · Berghauser Strasse 40 · 42859 Remscheid · Germany · main phone no. +49 2191 18-0 · Telefax +49 2191 18-2810 · www.vaillant-group.com
Ltd. company · Registered office: Remscheid · Registry court: Amtsgericht Wuppertal HRB 11775
Managing Directors: Dr Carsten Voigtländer (CEO), Dr Andree Groos, Dr Dietmar Meister, Dr Norbert Schiedeck · Chairman of the Supervisory Board: Dr Matthias Blaum
Commerzbank Remscheid (code 340 400 49) account no. 621 833 300 · IBAN DE67 3404 0049 0621 8333 00 · BIC-Code COBADEFF340 · USt-IdNr. DE 811142240



Please be assured that this decision was by no means an easy one. However, considering the foregoing we had to come to such a decision. We are of course prepared to explain further details.

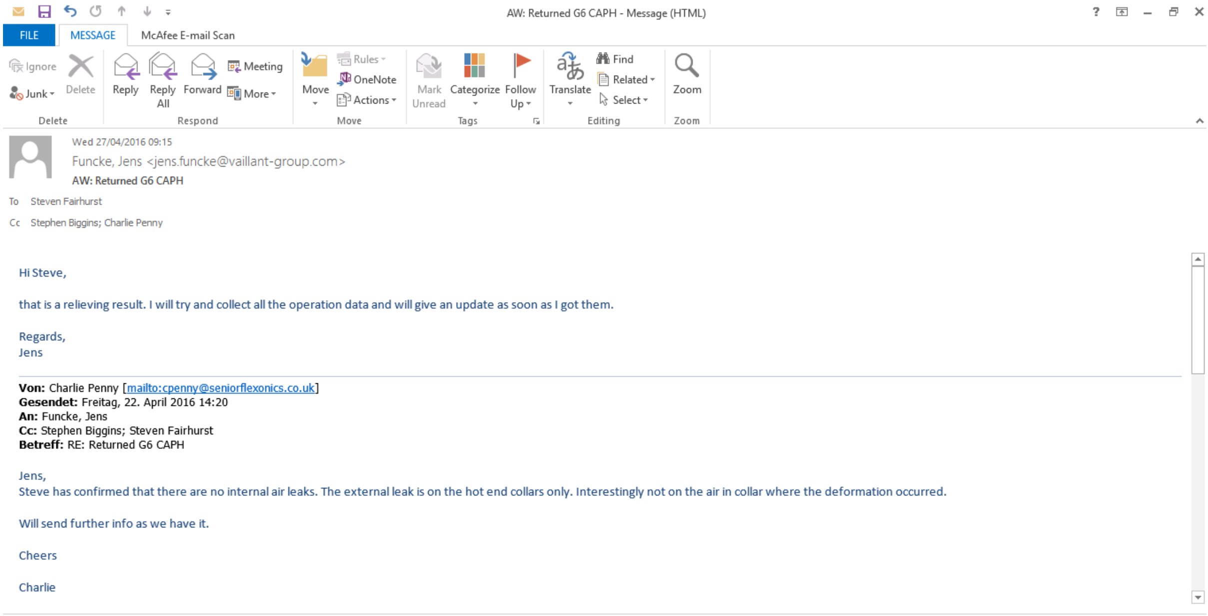
We therefore herewith terminate our participation in the Grant Agreement and request that you as coordinator terminate our participation accordingly. Please inform the JU accordingly and use this letter as a supporting document for the amendment letter for the HEATSTACK project. According to Section 3.2 of the Consortium Agreement our termination of participation in the Grant Agreement shall automatically terminate our participation Consortium Agreement.

Yours sincerely,
Vaillant GmbH

Dr. Norbert Schiedeck

ppa. Dr. Jürgen Sterlepper

11.4 Appendix 4 – Short chain of emails on original failure



Wed 27/04/2016 09:15
Funcke, Jens <jens.funcke@vaillant-group.com>
AW: Returned G6 CAPH
To Steven Fairhurst
Cc Stephen Biggins; Charlie Penny

Hi Steve,

that is a relieving result. I will try and collect all the operation data and will give an update as soon as I got them.

Regards,
Jens

Von: Charlie Penny [mailto:cpenny@seniorflexonics.co.uk]
Gesendet: Freitag, 22. April 2016 14:20
An: Funcke, Jens
Cc: Stephen Biggins; Steven Fairhurst
Betreff: RE: Returned G6 CAPH

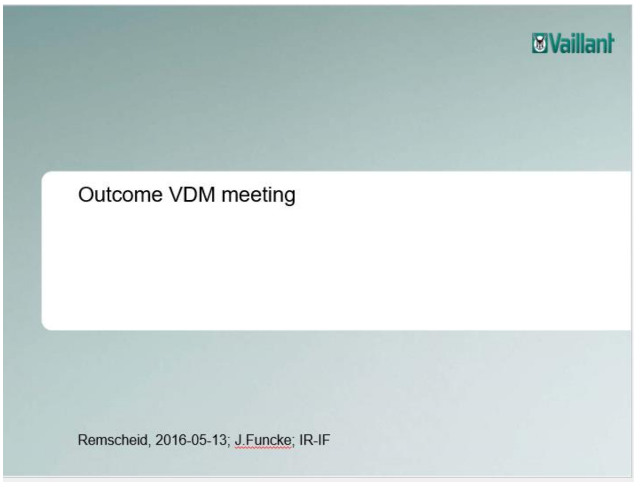
Jens,
Steve has confirmed that there are no internal air leaks. The external leak is on the hot end collars only. Interestingly not on the air in collar where the deformation occurred.

Will send further info as we have it.

Cheers

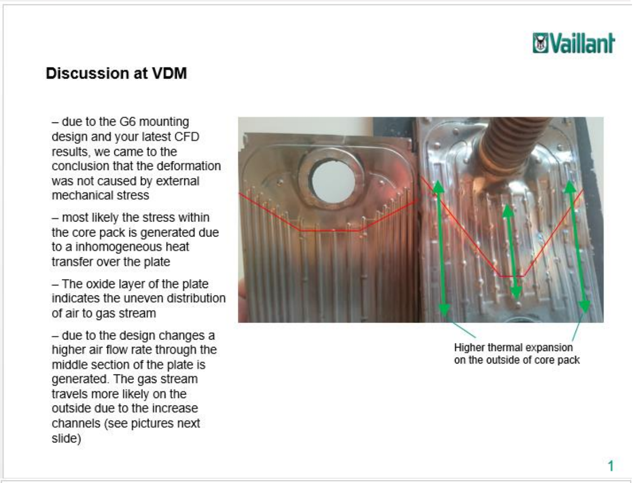
Charlie

11.5 Appendix 5 – Presentation on outcome of VDM meeting



Outcome VDM meeting

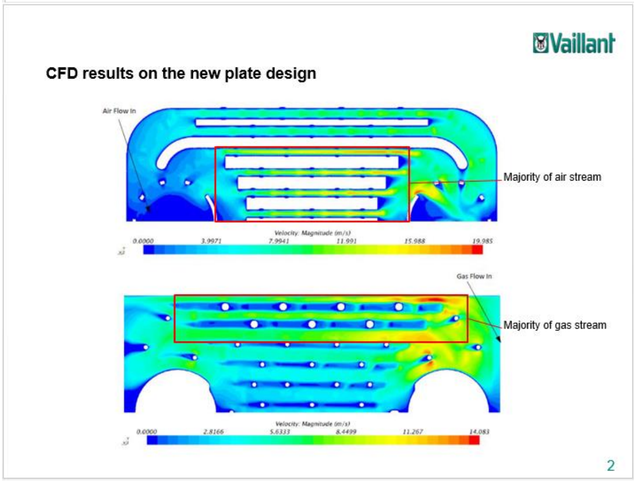
Remscheid, 2016-05-13; J.Funcke; IR-IF



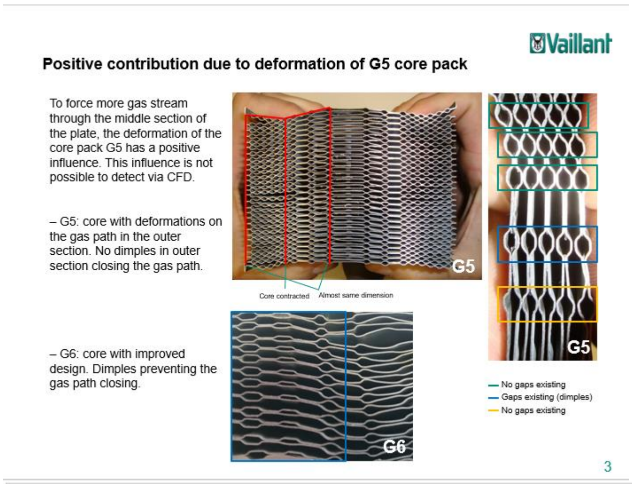
Discussion at VDM

- due to the G6 mounting design and your latest CFD results, we came to the conclusion that the deformation was not caused by external mechanical stress
- most likely the stress within the core pack is generated due to a inhomogeneous heat transfer over the plate
- The oxide layer of the plate indicates the uneven distribution of air to gas stream
- due to the design changes a higher air flow rate through the middle section of the plate is generated. The gas stream travels more likely on the outside due to the increase channels (see pictures next slide)

Higher thermal expansion on the outside of core pack



CFD results on the new plate design

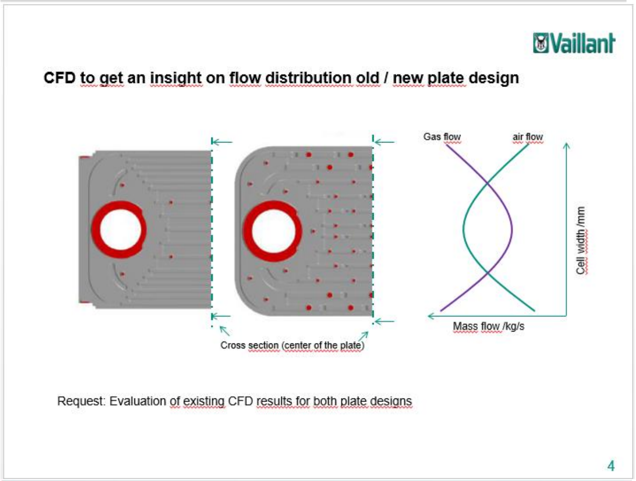


Positive contribution due to deformation of G5 core pack

To force more gas stream through the middle section of the plate, the deformation of the core pack G5 has a positive influence. This influence is not possible to detect via CFD.

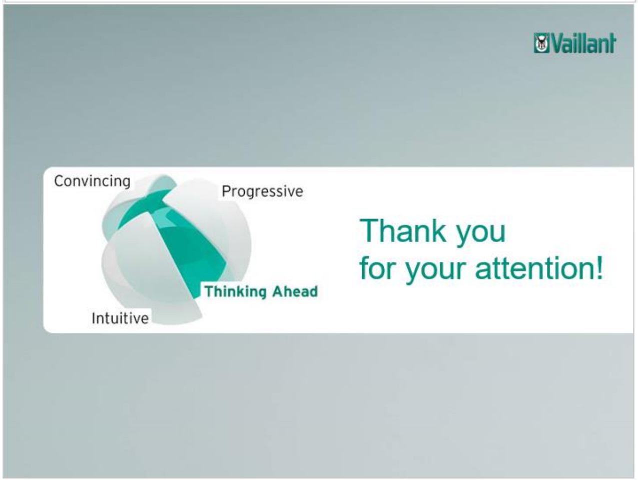
– G5: core with deformations on the gas path in the outer section. No dimples in outer section closing the gas path.

– G6: core with improved design. Dimples preventing the gas path closing.



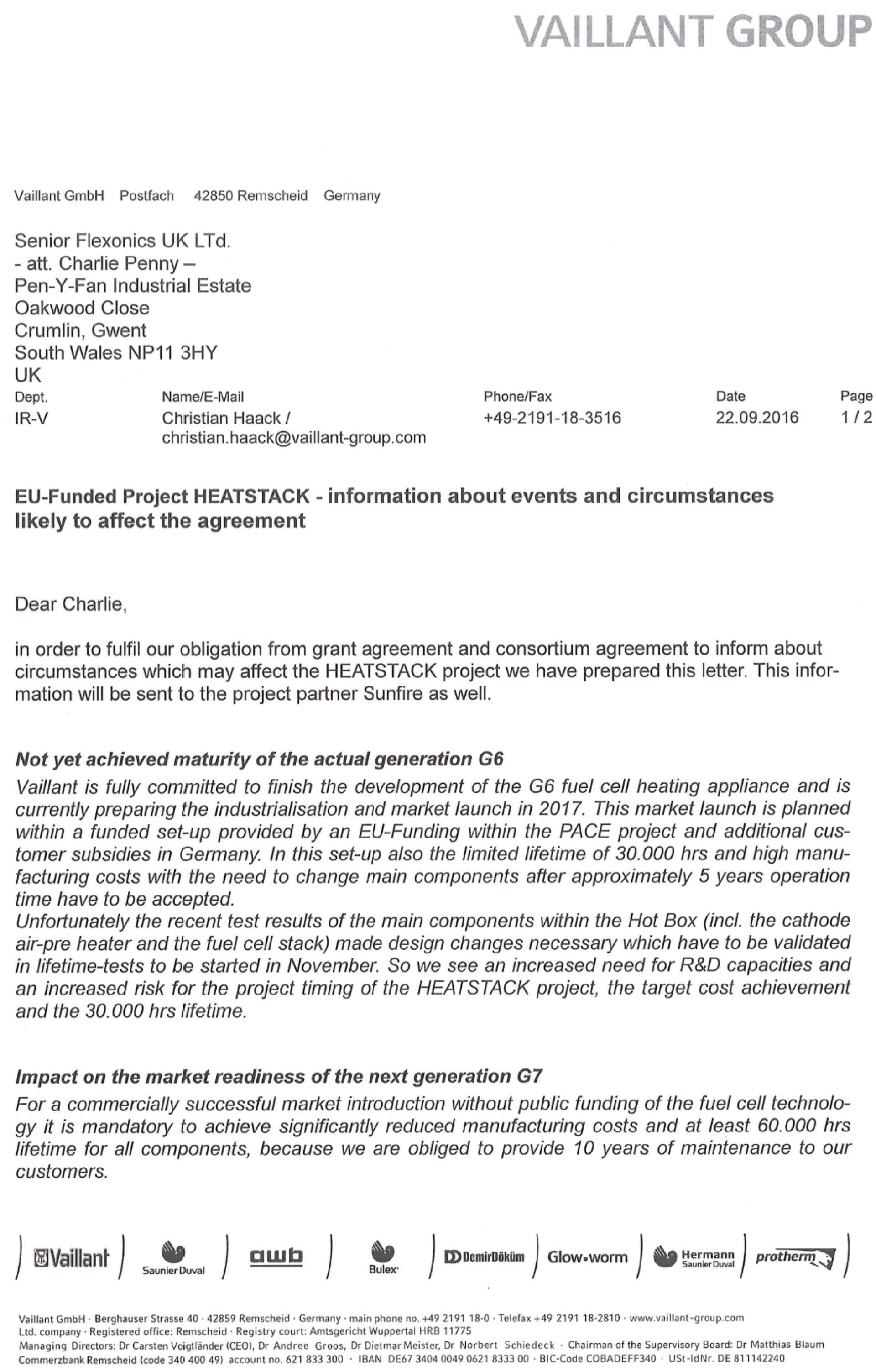
CFD to get an insight on flow distribution old / new plate design

Request: Evaluation of existing CFD results for both plate designs



Thank you
for your attention!

11.6 Appendix 6 – Initial letter from Vaillant



VAILLANT GROUP

Vaillant GmbH Postfach 42850 Remscheid Germany

Senior Flexonics UK LTd.
- att. Charlie Penny –
Pen-Y-Fan Industrial Estate
Oakwood Close
Crumlin, Gwent
South Wales NP11 3HY
UK

Dept.	Name/E-Mail	Phone/Fax	Date	Page
IR-V	Christian Haack / christian.haack@vaillant-group.com	+49-2191-18-3516	22.09.2016	1 / 2

EU-Funded Project HEATSTACK - information about events and circumstances likely to affect the agreement

Dear Charlie,

in order to fulfil our obligation from grant agreement and consortium agreement to inform about circumstances which may affect the HEATSTACK project we have prepared this letter. This information will be sent to the project partner Sunfire as well.

Not yet achieved maturity of the actual generation G6

Vaillant is fully committed to finish the development of the G6 fuel cell heating appliance and is currently preparing the industrialisation and market launch in 2017. This market launch is planned within a funded set-up provided by an EU-Funding within the PACE project and additional customer subsidies in Germany. In this set-up also the limited lifetime of 30.000 hrs and high manufacturing costs with the need to change main components after approximately 5 years operation time have to be accepted.
Unfortunately the recent test results of the main components within the Hot Box (incl. the cathode air-pre heater and the fuel cell stack) made design changes necessary which have to be validated in lifetime-tests to be started in November. So we see an increased need for R&D capacities and an increased risk for the project timing of the HEATSTACK project, the target cost achievement and the 30.000 hrs lifetime.

Impact on the market readiness of the next generation G7

For a commercially successful market introduction without public funding of the fuel cell technology it is mandatory to achieve significantly reduced manufacturing costs and at least 60.000 hrs lifetime for all components, because we are obliged to provide 10 years of maintenance to our customers.

Vaillant | Saunier Duval | awb | Bulex | DemirDöküm | Glow•worm | Hermann Saunier Duval | protherm

Vaillant GmbH · Berghauser Strasse 40 · 42859 Remscheid · Germany · main phone no. +49 2191 18-0 · Telefax +49 2191 18-2810 · www.vaillant-group.com
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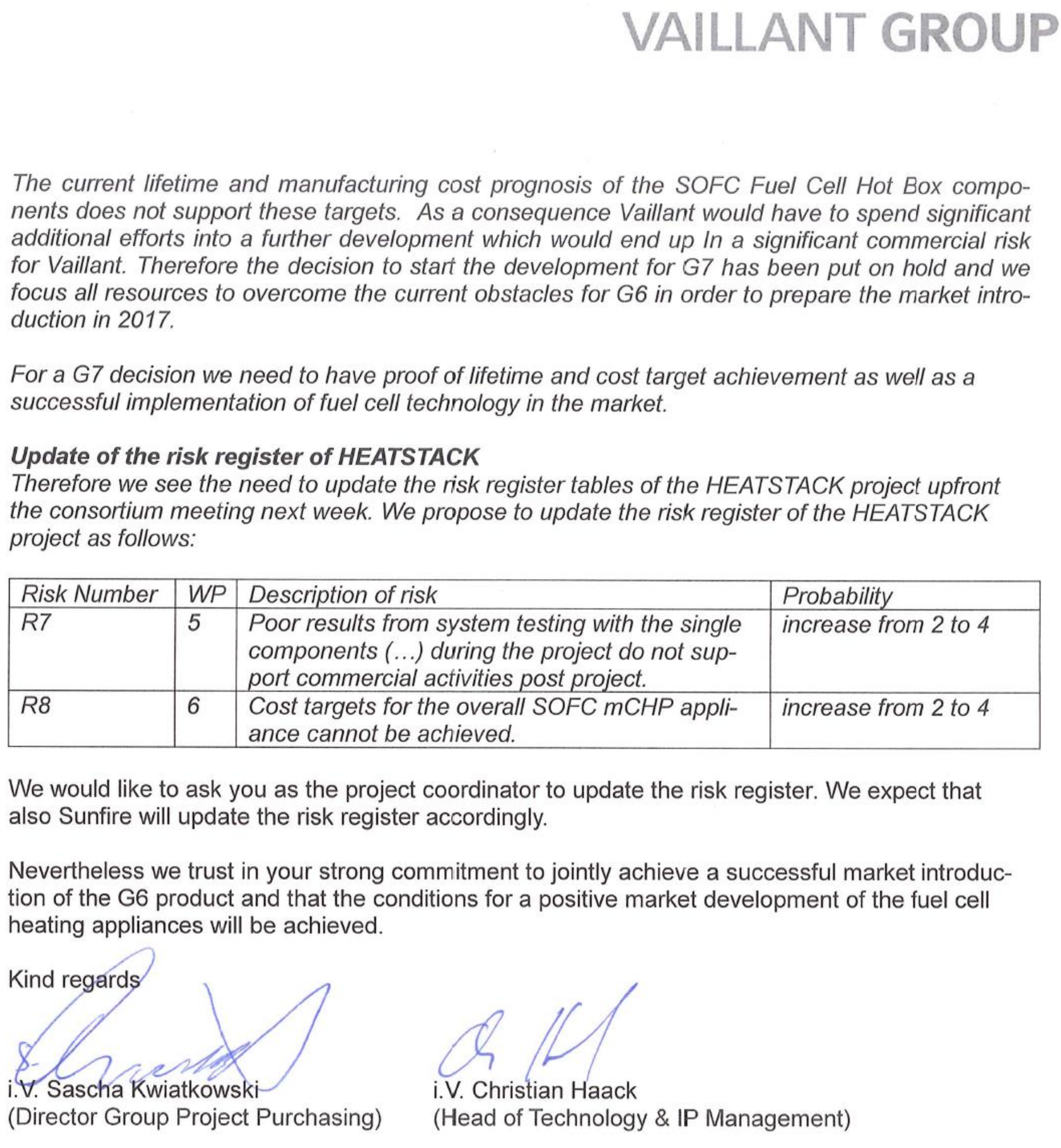


VAILLANT GROUP

The current lifetime and manufacturing cost prognosis of the SOFC Fuel Cell Hot Box components does not support these targets. As a consequence Vaillant would have to spend significant additional efforts into a further development which would end up In a significant commercial risk for Vaillant. Therefore the decision to start the development for G7 has been put on hold and we focus all resources to overcome the current obstacles for G6 in order to prepare the market introduction in 2017.

For a G7 decision we need to have proof of lifetime and cost target achievement as well as a successful implementation of fuel cell technology in the market.

Update of the risk register of HEATSTACK

Therefore we see the need to update the risk register tables of the HEATSTACK project upfront the consortium meeting next week. We propose to update the risk register of the HEATSTACK project as follows:

Risk Number	*WP*	*Description of risk*	*Probability*
R7	*5*	*Poor results from system testing with the single components (…) during the project do not support commercial activities post project.*	*increase from 2 to 4*
R8	*6*	*Cost targets for the overall SOFC mCHP appliance cannot be achieved.*	*increase from 2 to 4*

We would like to ask you as the project coordinator to update the risk register. We expect that also Sunfire will update the risk register accordingly.

Nevertheless we trust in your strong commitment to jointly achieve a successful market introduction of the G6 product and that the conditions for a positive market development of the fuel cell heating appliances will be achieved.

Kind regards

i.V. Sascha Kwiatkowski
(Director Group Project Purchasing)

i.V. Christian Haack
(Head of Technology & IP Management)

11.7 Appendix 7 – Termination letter from Vaillant

Hi Mirela

Good to hear from you. Yes we will use budget from other activities to cover this unexpected event.

Best regards

Charlie

From: ATANASIU Mirela (FCH) [mailto:Mirela.Atanasiu@fch.europa.eu]
Sent: 18 September 2016 15:55
To: Charlie Penny <cpenny@seniorflexonics.co.uk>
Cc: James Craven <james.craven@pnoconsultants.com>
Subject: RE: HEATSTACK

Dear Charlie,

Indeed, such risks cannot be foreseen and could be justified later, assuming you can take the budget from other activities.

Please confirm that this is the case.

BR,

Mirela

From: Charlie Penny [mailto:cpenny@seniorflexonics.co.uk]
Sent: 19 August 2016 10:06
To: ATANASIU Mirela (FCH)
Cc: James Craven
Subject: HEATSTACK

Hi Mirela,

I hope you are well.

During testing of heat exchangers supplied by Senior Flexonics, Crumlin to Vaillant some early failures where found. The failures were due to excessive distortion of the heat exchanger.

To resolve this Senior did a considerable amount of redesign supported by predictive analysis by a contractor and then manufacture of modified tooling to accommodate the design changes. The cost of these changes is circa €20,000

Although not stated as an activity in the original submission these changes were vital to deliver robust components and meet the goal of the HEATSTACK project. I assume that having the reports and the invoices we will legitimately able to claim this as part of HEATSTACK

Best regards

Charlie Penny

Product Development Director

11.8 Appendix 8 – email to FCH-JU

Hi Mirela,

Attached is a report from Jens Funcke, Vaillant.

Vaillant have found, during bench test thermal cycling testing two concerns with Senior's CAPH

1 Deformation of the plates.
2 Failure of the plate to end cap weld

I discussed by email the deformation of the plates with you (email attached) and a new palte design was developed and delivered to Vaillant

As described in the report the 2nd failure mode then occurred. We have put in place a design fix that is partly through proving test, but will not finish until February 2017. Hopefully, this will pass the test and Vaillant will be able to sign off the latest design.

Unfortunately this has led to delays in a number of our deliverables :-

D2.1 and D2.2 – although we have purchased the capital and tooling we now need to redesign/modify the tooling for the design changes. This then stops us from signing off the capital.

We have submitted the first report but D2.2 may need to be delayed to allow Senior to carry out the necessary modifications.

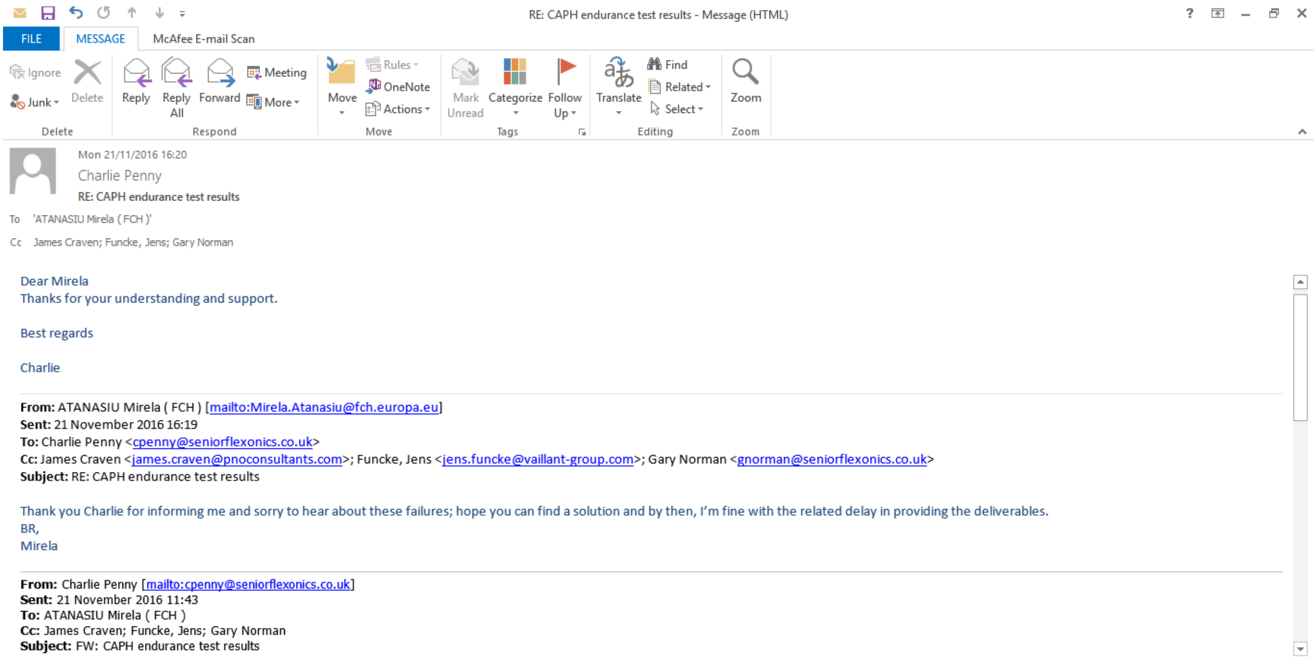
D5.1 – Senior need to build 160 CAPHs by month 13 of the project. As Vaillant we not be able to sign off the design until February 2017 we will not start on this until then. I'd like to give an interim report in month 13 showing the first parts being manufactured and complete the 160 by month 18. This will then cause D5.3 and D5.4 to slip.

I hope this is acceptable. Please let me know if it is.

Best regards

Charlie

11.9 Appendix 9 – email to and from FCH-JU



Mon 21/11/2016 16:20
Charlie Penny
RE: CAPH endurance test results
To 'ATANASIU Mirela (FCH)'
Cc James Craven; Funcke, Jens; Gary Norman

Dear Mirela
Thanks for your understanding and support.

Best regards

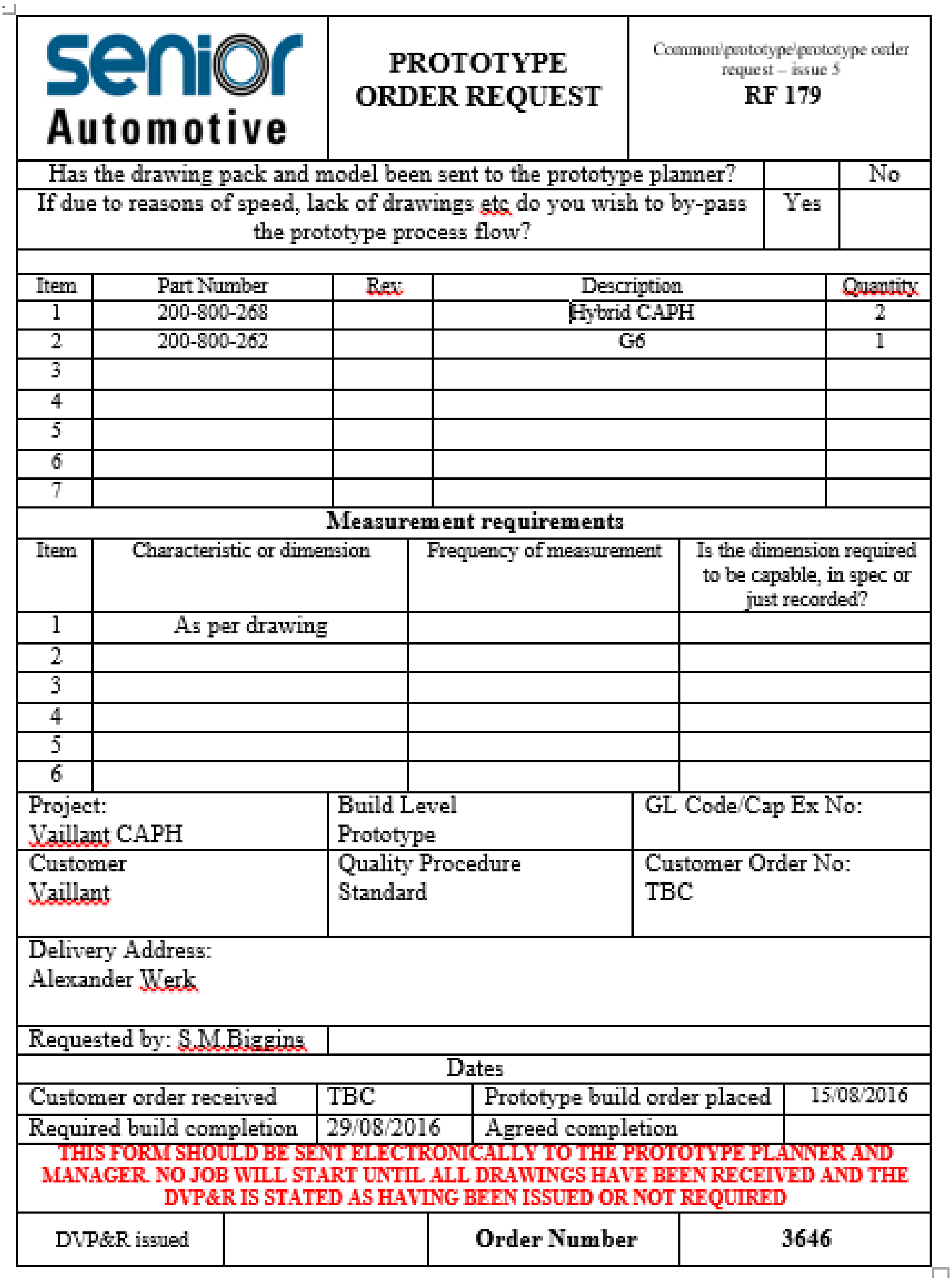
Charlie

From: ATANASIU Mirela (FCH) [mailto:Mirela.Atanasiu@fch.europa.eu]
Sent: 21 November 2016 16:19
To: Charlie Penny <cpenny@seniorflexonics.co.uk>
Cc: James Craven <james.craven@pnoconsultants.com>; Funcke, Jens <jens.funcke@vaillant-group.com>; Gary Norman <gnorman@seniorflexonics.co.uk>
Subject: RE: CAPH endurance test results

Thank you Charlie for informing me and sorry to hear about these failures; hope you can find a solution and by then, I'm fine with the related delay in providing the deliverables.
BR,
Mirela

From: Charlie Penny [mailto:cpenny@seniorflexonics.co.uk]
Sent: 21 November 2016 11:43
To: ATANASIU Mirela (FCH)
Cc: James Craven; Funcke, Jens; Gary Norman
Subject: FW: CAPH endurance test results

11.10 Appendix 10 – Prototype order for CAPHs with new plate design



senior Automotive	**PROTOTYPE ORDER REQUEST**	Common/prototype/prototype order request – issue 5 **RF 179**

Has the drawing pack and model been sent to the prototype planner?		No
If due to reasons of speed, lack of drawings etc do you wish to by-pass the prototype process flow?	Yes	

Item	Part Number	Rev	Description	Quantity
1	200-800-268		Hybrid CAPH	2
2	200-800-262		G6	1
3				
4				
5				
6				
7				

Measurement requirements

Item	Characteristic or dimension	Frequency of measurement	Is the dimension required to be capable, in spec or just recorded?
1	As per drawing		
2			
3			
4			
5			
6			

Project: Vaillant CAPH	Build Level Prototype	GL Code/Cap Ex No:
Customer Vaillant	Quality Procedure Standard	Customer Order No: TBC

Delivery Address:
Alexander Werk

Requested by: S.M.Biggins

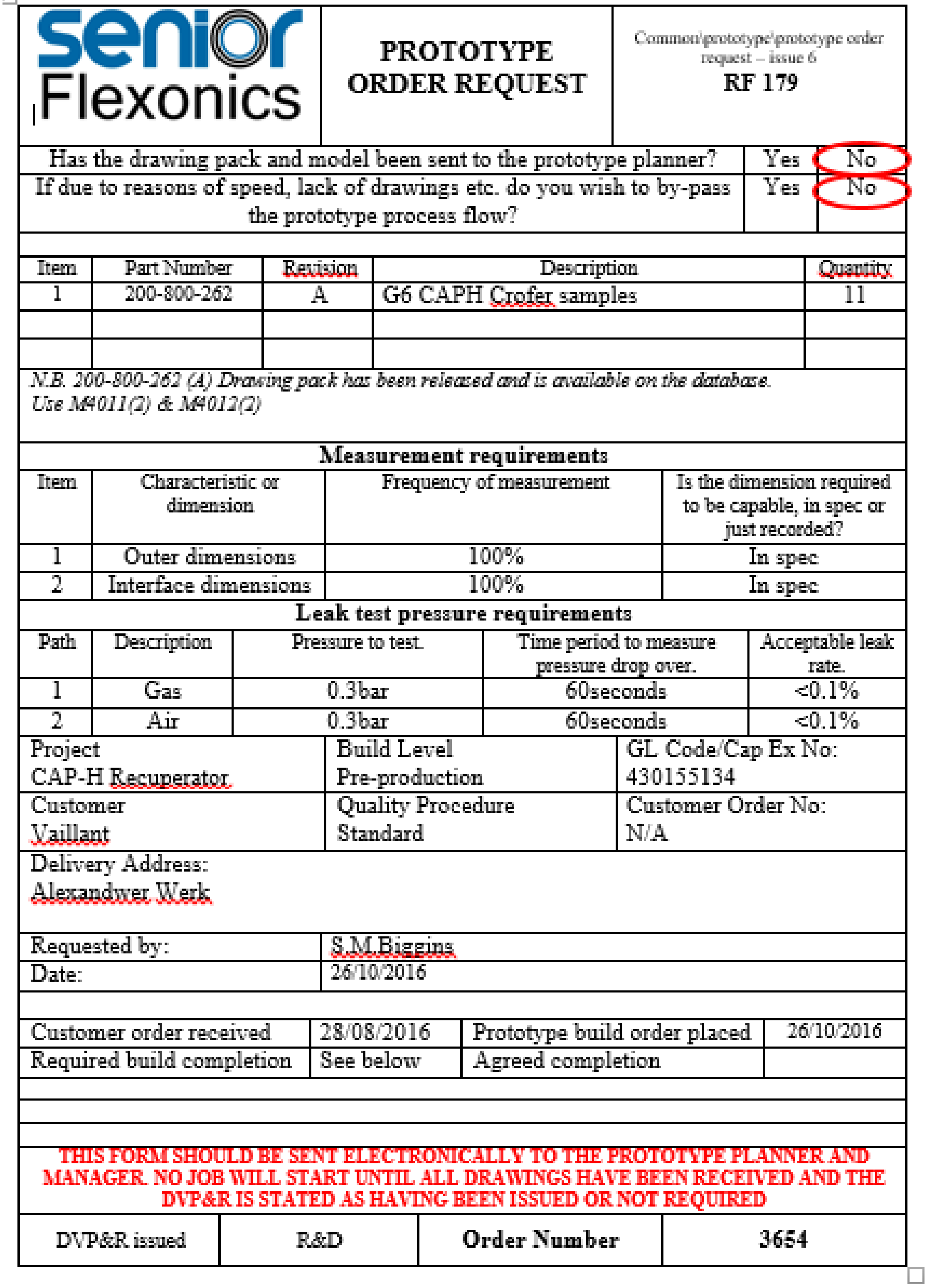
Dates

Customer order received	TBC	Prototype build order placed	15/08/2016
Required build completion	29/08/2016	Agreed completion	

THIS FORM SHOULD BE SENT ELECTRONICALLY TO THE PROTOTYPE PLANNER AND MANAGER. NO JOB WILL START UNTIL ALL DRAWINGS HAVE BEEN RECEIVED AND THE DVP&R IS STATED AS HAVING BEEN ISSUED OR NOT REQUIRED

DVP&R issued		**Order Number**	**3646**

11.11 Appendix 11 – Prototype order for CAPHs with new plate and weld ribs



senior Flexonics

PROTOTYPE ORDER REQUEST

Common/prototype/prototype order request – issue 6

RF 179

Has the drawing pack and model been sent to the prototype planner?	Yes	[✓ No]
If due to reasons of speed, lack of drawings etc. do you wish to by-pass the prototype process flow?	Yes	[✓ No]

Item	Part Number	Revision	Description	Quantity
1	200-800-262	A	G6 CAPH Crofer samples	11

N.B. 200-800-262 (A) Drawing pack has been released and is available on the database.
Use M4011(2) & M4012(2)

Measurement requirements

Item	Characteristic or dimension	Frequency of measurement	Is the dimension required to be capable, in spec or just recorded?
1	Outer dimensions	100%	In spec
2	Interface dimensions	100%	In spec

Leak test pressure requirements

Path	Description	Pressure to test.	Time period to measure pressure drop over.	Acceptable leak rate.
1	Gas	0.3bar	60seconds	<0.1%
2	Air	0.3bar	60seconds	<0.1%

Project CAP-H Recuperator	Build Level Pre-production	GL Code/Cap Ex No: 430155134
Customer Vaillant	Quality Procedure Standard	Customer Order No: N/A

Delivery Address:
Alexandwer Werk

Requested by:	S.M.Biggins
Date:	26/10/2016

Customer order received	28/08/2016	Prototype build order placed	26/10/2016
Required build completion	See below	Agreed completion	

THIS FORM SHOULD BE SENT ELECTRONICALLY TO THE PROTOTYPE PLANNER AND MANAGER. NO JOB WILL START UNTIL ALL DRAWINGS HAVE BEEN RECEIVED AND THE DVP&R IS STATED AS HAVING BEEN ISSUED OR NOT REQUIRED

DVP&R issued	R&D	**Order Number**	**3654**

11.12 Appendix 12 – Supplier orders for CAPHs

Order No	Order Date	Description	QTY	Total	Supplier
C057191	27/04/2016	3015-100-1592 REV B / 3015-100-1593 REV B	2850	2,137.50	PRESSTEC TOOLING LTD
C057191	27/04/2016	3015-100-1592 REV B / 3015-100-1593 REV B	1850	1,387.50	PRESSTEC TOOLING LTD
C057192	27/04/2016	3015-100-1616/3015-100-1617/3015-100-1620	751	2,268.44	SAFELOK COMPONENTS LTD
C057190	27/04/2016	BELLOWS 25MMX.2XX 316 BELLOWS VAILLANT	10	20.50	SENIOR FLEXONICS GMBH
C057203	13/06/2016	ALUCHROME 318 WNB 245.5MMX0.3MM STRIP	846	16,708.50	VDM (UK) LIMITED
C057364	23/06/2016	DEV/TOOLING	1	1,875.00	RUDRA CASTINGS PRIVATE LIMITED
C057401	04/07/2016	3015-100-1619 REV 10 END CAP - VAILLANT	1025	2,009.00	SUBCON LASER CUTTING LTD
C057490	27/07/2016	3015-100-1593 ALU LONG PLATE/ SET UP CHARGE	100	150.00	PRESSTEC TOOLING LTD
C057536	16/08/2016	0102-100-457 HYDRO STRAIGHT TUBE	10	106.84	SENIOR FLEXONICS GMBH
C057540	17/08/2016	3015-100-1684/3915-100-1689/3015-100-1683/3015-100-1685/3015-100-1681/3015-100-1682	21	1,455.00	PRESSTEC TOOLING LTD
C057589	08/09/2016	3015-100-1270 REV A BLANKING DISC	2000	580.00	SUBCON LASER CUTTING LTD
C057611	19/09/2016	SPACER TOOL MOD - 3015-100-1489	1	1,880.00	PRESSTEC TOOLING LTD
C057610	19/09/2016	3015-100-1616/3015-100-1617/3015-100-1620	1351	4,243.21	SAFELOK COMPONENTS LTD
C057637	26/09/2016	MODIFY 3015-100-1615 AIR INTERFACE COLLAR	50	240.00	PRESSTEC TOOLING LTD
C057644	03/10/2016	TOOLING MOD TO VAILLANT GAS PLATE TOOLING	1	6,800.00	PRESSTEC TOOLING LTD
C057647	03/10/2016	M4011 END CAP / M4012 WELDING RIB	24	813.60	PRESSTEC TOOLING LTD
C057674	10/10/2016	CROFTER MATERIAL SHEET QN6600035533	1	1,250.00	VDM METALS GMBH
C057719	26/10/2016	M4011 (2) END CAP / M4012 (2) WELDING RIB	20	801.00	PRESSTEC TOOLING LTD
C057720	26/10/2016	CASTING MACHINE	1	260.00	PRESSTEC TOOLING LTD
C057786	22/11/2016	LASER WELD 23.11.16	1	37.50	CARRS WELDING TECHNOLOGIES
C057786	22/11/2016	LASER WELD 23.11.16	1	400.00	CARRS WELDING TECHNOLOGIES
16600023/14	02 & 06/12/2016	Laser Weld Vaillant G6 Prototypes & LASER WELD 6 VALIANT UNITS=AIR PIPES- SPACERS X 6	5	1,712.50	CARRS WELDING
16600032	09/12/2016	Laser Weld Vaillant	1	100.00	CARRS WELDING
16600055	19/12/2016	CROFER 3.5 X 1000 X 1000 SS MATERIAL	6	6,552.00	VDM
17600004	09/01/2017	Machining Operation on 44 Vaillant End caps	44	224.40	PRESSTEC TOOLING LTD
17600009	10/01/2017	Annealed Alloy 625 Strip Coil with Sheared Edges to AMS 5599	141	7,600.00	QUEST4ALLOYS
17600025	11/01/2017	289-5428	1	23.85	RS COMPONENETS
17600074	13/01/2017	Use of Furnace 02-02-2017	1	200.00	KEPSTON
17600051	23/01/2017	3015-100-1615(B) AIR INTERFACE COLLAR	30	180.30	SAFELOK
17600054	23/01/2017	3015-100-1616(B) LONG INTERFACE COLLAR (10) / 3015-100-1617 (B) SHORT INTERFACE COLLAR / 3015-100-1620 GAS IN PIPE	975	2,605.20	SAFELOK
17600062	25/01/2017	FAILURE ANALYSIS REPORT 2K17-1	1	300.00	CAMBRIDGE METALS
17600060	25/01/2017	3015-100-1618(B) & MACHINED CROFER END PLATES & WELD RIB SETS	30	401.00	PRESSTEC TOOLING LTD
17600077	01/02/2017	Crofer Weld Rib Sets- 3015-1002017 Rev A & Aluchrome Side Walls 3015-100-1618 Rev B	100	1,495.00	PRESSTEC TOOLING LTD
17600095	07/02/2017	SS 309 Short & Long Half Plate Tool Set up, Trials, C/Overs & Sidewall (3015-100-2004) Tooling	2	3,250.00	PRESSTEC TOOLING LTD
17600097	09/02/2017	3015-100-1489 (A) Pressed Spacer	3000	1,800.00	PRESSTEC TOOLING LTD
17600102	10/02/2017	3015-100-2003 End Caps / 3015-100-2006 Conicalo Reducer / 3015-100-2007 Air Tube / 3015-100-2008 Collar / 3015-100-2009 Gas Pipe / 3015-100-2010 Top & Bottom Plate / 3015-100-2011 Side Plate / 3015-100-2012 Edge Support / 3015-100-1996 Long Pressed Half Plate / 3015-100-1997 Short Pressed Half Plate / 3015-100-2004 Side Wall	373	2,987.64	PRESSTEC TOOLING LTD
17600107	14/02/2017	Laser weld 5 Vaillant Parts	1	398.75	CARRS WELDING
17600116	16/02/2017	PUK U5-U5-555-000 / "Welding Microscope SMG5 200-207-G5e (10% Discount)" / PUK Flow Regulator 100-600-GB / Optic Unit 100-210e / T-Connector 100-823e / Foot Switch 100-850c / Electrode Sharpner Including Wall Power 100-856e / Electrodes Ecopack 10 pieces (0.8mm) 100-443e / Handpiece Cradle 100-112e / Welding Table Complete with Cable 100cm 100-300e	10	4,654.59	LAMPERT
17600124	21/02/2017	0107-510-922 - 2 BELLOWS/STICK	3	9.00	SENIOR CAPETOWN
17600133	24/02/2017	Adaptor Socket 6mm to 4mm	1	22.71	LAMPERT
17600131	24/02/2017	Manufacture & Assemble Tack Welding Fixture / Material & Bought Out parts / Design	3	1,600.00	BRECON DESIGNS
17600159	02/03/2017	Mods to X005538 Leak Test Fixture / Mods to X005554 Laser weld Fixture	2	1,160.00	BRECON DESIGNS
17600151	02/03/2017	3015-100-1996 Long Pressed Half Plate (SS309) / Changeover/Set Up & run to produce long plate	11	291.90	PRESSTEC TOOLING LTD
17600175	08/03/2017	3015-100-2062 AIR INTERFACE COLLAR	8	504.00	PRESSTEC TOOLING LTD
17600194	14/03/2017	Humpback Belt Furnace	1	200.00	KEPSTON
17600205	20/03/2017	0.4mmT x Ø33mm x 1M Length	6	300.00	SENIOR CAPETOWN
17600208	21/03/2017	3015-100-2003 END CAP	6	456.00	PRESSTEC TOOLING LTD
17600210	21/03/2017	3015-100-2073 Diffuser 0.5mm Stainless Steel, 304	3	108.00	PRESSTEC TOOLING LTD
17600209	21/03/2017	3015-100-2021 Welding Rib Set	12	390.00	PRESSTEC TOOLING LTD