FME HighEFF

Centre for an Energy Efficient and Competitive Industry for the Future

Deliverable D5.2_2019.05
NEC#2 HighEX

Delivery date: 2019-12-12

Organisation name of lead partner for this deliverable:

SINTEF IND

HighEFF- Centre for an Energy Efficient and Competitive Industry for the Future is one of Norway's Centre for Environment-friendly Energy Research (FME). Project co-funded by the Research Council of Norway and Industry partners. Host institution is SINTEF Energi AS.		
Dissemination Level		
PU	Public	x
RE	Restricted to a group specified by the consortium	
INT	Internal (restricted to consortium partners only)	

Deliverable number:	D5.2_2019.05
ISBN number:	
Deliverable title:	NEC#2 HighEX
Work package:	WP5.2
Deliverable type:	NEC
Lead participant:	SINTEF ER

Quality Assurance, status of deliverable		
Action	Performed by	Date
Verified (WP leader)	Arne Petter Ratvik	2019-12-12
Reviewed (RA leader)	Ingrid Camilla Claussen	2019-12-12
Approved (dependent on nature of deliverable)*)		

*) *The quality assurance and approval of HighEFF deliverables and publications have to follow the established procedure. The procedure can be found in the HighEFF eRoom in the folder "Administrative > Procedures".*

Authors		
Author(s) Name	Organisation	E-mail address
Trond Andresen	SINTEF ER	Trond.Andresen@sintef.no

Abstract

The revised application is describing HighEFF's second granted novel emerging concept (NEC) project; *HighEx: Design for additive manufacturing of novel heat exchangers,* which will be led by SINTEF ER and performed together with SINTEF IND.

The project aims to investigate the influence of the additive manufacturing (AM) process itself on the produced object, and describe and validate a workflow to mitigate or even exploit these effects, an approach well beyond state of the art.

The project period is August 2019 until May 2020 with a total budget of NOK 1 200 000.

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Additional information requested for project startup

Timeline:

- The GANTT table has been updated to reflect a linear shift due to delayed startup
- The project aims to conclude within Q2 2020, in order to have results and main findings ready for presentation at the spring consortium meeting in May.

Industry reference group:

- We will invite a few relevant industry partners to join an industry reference/evaluation group
- This group may provide input to the work, and evaluate prospective follow up opportunities
- Potential candidate end users: Hydro, Alcoa, Equinor
- Potential candidate vendors: Alfalaval, GE Power Norway

Formal deliverables:

- Blog + newsletter
- Arrange industry reference group meeting(s)
- Metal "HX geometry" samples produced using AM
- Presentation HighEFF spring meeting
- "Follow-up" suggestions to reference group
- Final report

Budget distribution:

		hour costs		direct costs	
	Tot	2019	2020	2019	2020
SUM SER	550	360	175	15	0
SUM SI	580	225	215	0	100
Contingency	70	0	30	0	40
SUM total	1200	585	460	15	140

Current detailed activity plan (available in excel format):

Activity	Outcome	Formal deliverable	Due	Responsible	SUM hour costs	Direct costs
Administration, communication	Administration, follow up with NEC-admin		-	Trond	70	-
	Blog, newsletter, other	Y	2019-09	Trond	25	-
	Arrange Industry reference group meeting	Y	2019-10	Trond	40	15
	Presentation HighEFF spring meeting	Y	2020-05	All	30	-
	"Follow up" suggestions to reference group	Y	2020-05	All	20	-
3D design model	Designing HX concepts, constructing STL-models of 2 samples, size limit 10x10x10 cm		2019-09	Trond	150	-
	Redesign HX in interaction with FEM-analysis, reduce thermal stress		2019-11	Trond	125	-
Preparation of models for AM	FEM analysis, identification of problem areas (w.r. to deformation)		2019-10	Xiang	125	-
	Revision of FEM analysis with revised STL-model, make final AM model		2019-12	Xiang	100	-
Manufacturing of samples	Hours - Manufacture of 2 samples in metal (aluminium, and/or steel, titanium)	Y	2020-01	Amin	100	-
	Direct costs - Manufacture of 2 samples in metal (aluminium, and/or steel, titanium)		2020-01	Amin	-	100
					-	-
					-	-
Validation of samples	Validating actual physical dimentions vs. Target		2020-01	All	40	-
	Measuring surface roughness		2020-01	Amin	40	-
Result analysis and reporting	Final summarizing report, containing: (**Main formal deliverable**)	Y	2020-05	Trond	40	-
	Local HX design features and impact on thermal stresses/deformation		2020-05	Mohammed	20	-
	Validation of FEM model for thermal deformation preduction/mitigation		2020-05	Mohammed	20	-
	Designing HX geometry features suitable for AM manufacture		2020-05	Trond	20	-
	Potential for efficient HX designs by AM manufacture		2020-05	Trond	20	-
	Summarizing manufacture of samples (equipment specification, parameters, experiences)		2020-05	Amin	15	-
	Validation of surface roughness in manufactured samples		2020-05	Amin	15	-
Contingency	Contingency			t.b.d	30	40

HighEx targets three of HighEFF's overall goals: "reduction in specific energy use", "innovative solutions", "methods and tools"

HighEx: Design for additive manufacturing of novel heat exchangers

Research institution: SINTEF Energy Research, SINTEF Industry
Contact person: Trond Andresen, trond.andresen@sintef.no
Project period: August 2019 – May 2020
Budget: NOK 1 200 000

Heat exchangers (HX) are crucial industrial components utilized in countless thermal processes across all industry sectors. Heat exchanger technologies are being developed on several fronts such as performance, cost, and energy- and material efficiency. Substantial progress is undertaken by the manufacturers, but the major focus is still on improving or optimizing specific heat exchanger types and technologies. The designers have set design boundary conditions that is controlled by the 'manufacturability' of the designs. However, modern material processing methods such as additive manufacturing (AM), provide new opportunities for optimal design and advanced technology integration in this field[1]. The proposed project will be a significant contribution to the big innovation question: "What new potential could be realised if heat exchanger design and manufacture are decoupled from current production methods and associated constraints".

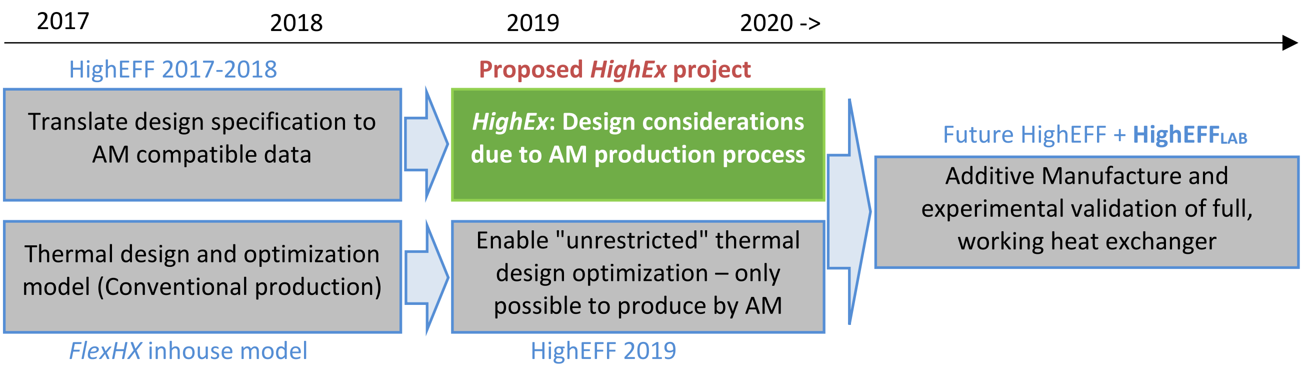
Concept description

HighEx aims to investigate the influence of the AM process itself on the produced object, and describe and validate a workflow to mitigate or even exploit these effects, an approach well beyond state of the art. Producing highly complex heat exchangers using the powder bed laser fusion (PBLF) technology will unavoidably cause thermal stress (deformations) and areas with relatively high surface roughness. In a heat exchanger, this will affect heat transfer and pressure losses. It is crucial to mitigate these effects, and ideally take them into consideration in the actual design. Thus, the ***main objectives*** of the proposed project are:

(i) *Establish the PBLF metal processing workflow for heat exchanger manufacturing*
(ii) *Identify optimum process parameters using recently developed numerical and experimental tools*
(iii) *Utilize the limitations of the technology (e.g. rough as-built surfaces) as an advantage in processing of efficient heat exchangers*
(iv) *"3D-print" heat exchanger samples in aluminium, and characterize the finished products*
(v) *Establish a baseline and provide recommendations for further development of Additive Manufacturing of heat exchangers*

Alignments with HighEFF overall objectives

The proposed project constitutes an essential development step towards enabling final design, manufacture and experimental validation of functional novel HX concepts produced with AM. While other activities within HighEFF concentrate on thermal- and flow related aspects of HX development, *HighEx* aim to solve important mechanical aspects originating from the actual production process, that must be mitigated or even exploited during the design and/or process workflow. Successful completion of the activities in **HighEx is crucial** to enable AM processing of complete, working HX concepts for laboratory testing in HighEFF$_{LAB}$. The context of the proposed *HighEx* project in relation to related HighEFF activities is illustrated in the figure below.



[1] Neugebauer, Reimund, et al. "Additive manufacturing boosts efficiency of heat transfer components." Assembly Automation 31.4 (2011): 344-347.

Plan and budget

1. **3D design model** - Constructing a 3D specification of the HX sample, based on the inhouse heat exchanger design framework *FlexHX*[2]. The material of choice will be aluminium due to superior thermal properties, relevance for novel heat exchanger concepts, and availability for the PBLF-process.
2. **Preparation of models for AM** – Input from 1) will be fed into a finite element numerical models of the AM process, with the objective of modifying the design details towards "first-time-right" processing of the HX component. Outcomes of this step are thermal, stress, strain and phase constituent fields.
3. **Design considerations for production method** – Inherent side-effects of the AM processing such as deformation and orientation-dependent surface roughness will be evaluated to improve heat exchanger performance. Results from 2) and 3) will feed back into 1) for design iterations until desired result. The objective is to maximize the dimensional accuracy and structural integrity of the components.
   a. **Deformation** – The printed object deforms during manufacture due to uneven thermal stresses. Deformation is more pronounced in the objects with variable thickness or abrupt changes in geometry – both featured in heat exchangers. Deviations in the final object can be minimized by either compensating for deformation[3] in the design, or by altering the design for more even stresses.
   b. **Surface roughness** is important to heat exchanger performance as it impacts both heat transfer and pressure drop. Higher roughness objects also have reduced fatigue resistance and are more prone to fouling. The roughness of PBLF objects can be influenced by printing parameters and object orientation on the work surface[4]. The surface roughness should be optimised to give the required fatigue strength and heat exchanging capacity, while reducing the fouling possibility. For this purpose, formerly developed open source analytic codes will be utilised.
4. **Manufacturing and validation of HX samples** - Partitions of designed HX's containing representative combinations of local geometry features will be manufactured using PBLF. The produced samples will be measured and analysed with respect to deformation and surface roughness to validate, and potentially revise, the methodology for design considerations under item 3).
5. **Evaluate AM for heat exchanger production** – Discuss and assess opportunities and limitations for use of AM in manufacturing of heat exchangers based on undertaken work, experiences and achieved results. Recommendations for further development and utilization of AM heat exchangers.

Tasks	Partner	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Budget
1.1. Initial design of novel HX	ER											175
1.2. AM ready specification	ER											150
2.1. Manufacturability studies	IND											175
3.1 Analysis, design revision	ER/IND											250
4.1. AM samples manufacture	IND											200
4.2. Samples characterization	IND											100
5.1. Reporting, recommendations	ER/IND											150
												1200

Market potential

Establishing an integrated design workflow and a controlled, practical production process has large and broad potential: Commercial product development, limited-series production for special applications, rapid prototyping, etc. Succeeding in the long-term goal of applying this process to design and produce more efficient heat exchangers would be applicable to all kinds of thermal processes and cycles, and thus has very large potential impact, economically and environmentally.

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[2] Skaugen, G., Kolsaker. K., Walnum, H.T., Wilhelmsen, Ø. "A flexible and robust modelling framework for multi-stream heat exchangers," Computers & Chemical Engineering, vol. 49, no. , pp. 95-104, 2013

[3] Huang, Qiang. "An analytical foundation for optimal compensation of three-dimensional shape deformation in additive manufacturing." Journal of Manufacturing Science and Engineering 138.6 (2016): 061010.

[4] Hovig, Even W., et al. "High cycle fatigue life estimation of materials processed by laser powder bed fusion." Fatigue & Fracture of Engineering Materials & Structures (2019).