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3D PRINTING SCALE MODEL FOR EDUCATIONAL PURPOSES

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Abstract: *Oil and gas engineering company has printed 3D scale model of heat exchanger, which enable them to show their customers and new employees how all the different parts work together. If it is true that a picture is worth a thousand words, then a physical model is worth a thousand pictures. They create a three-dimensional scale model of an object using a computer-aided design (CAD) program, and produce model on 3D printer.*

Key Words: ***Rapid prototyping, Direct manufacturing, Solid freeform fabrication, Additive manufacturing, STL (STereoLithography), 3D model, 3D printing, Scale model, Heat exchanger, Pressure vessel, Oil and gas engineering***

1. INTRODUCTION

The "Hitard Engineering" was founded in February 1995 in Rotterdam, the Netherlands and it has been successfully operating for nearly two decades. The primary activity of the company is the design and engineering of plants for the processing industry.

Constant growth and development, secured through quality service, has classified "Hitard Engineering" in the top leading companies in the field of engineering. This has led to the need to expand capacity to work, which resulted in establishing a branch in Qatar in 2003, that worked until 2006, when it established a representative office in Novi Sad, in cooperation with the Faculty of Technical Sciences in Novi Sad. "Hitard Engineering" has achieved long-term cooperation with educational and research institutions in the Netherlands and Serbia.

Plants for the processing industry are usually inaccessible, which means that employees are only theoretically acquainted with devices that project. For the purpose of Instructional Design, company has printed 3D scale model of heat exchanger, which enables them to show their customers and new employees how all the different parts work together.

2. HEAT EXCHANGERS

The general function of a heat exchanger is to transfer heat from one fluid to another. The basic component of a heat exchanger can be viewed as a tube with one fluid running through it and another fluid flowing by on the outside. There are three heat transfer operations [1]:

1. Convective heat transfer from fluid to the inner wall of the tube,
2. Conductive heat transfer through the tube wall,
3. Convective heat transfer from the outer tube wall to the outside fluid.

Heat exchangers are typically classified according to flow arrangement and type of construction. The simplest heat exchanger is one for which the hot and cold fluids move in the same or opposite directions in a concentric tube (or double-pipe) construction. In the parallel-flow arrangement, the hot and cold fluids enter at the same end, flow in the same direction, and leave at the same end. In the counterflow arrangement, the fluids enter at opposite ends, flow in opposite directions, and leave at opposite ends. Alternatively, the fluids may be in cross flow (perpendicular to each other) [1].

2.1. TEMA (Tubular Exchange Manufacturers Association) Type Heat Exchangers

TEMA is a set of standards developed by leading heat exchanger manufacturers that define the heat exchanger style and the machining and assembly tolerances to be employed in the manufacturing of a given unit. TEMA stands for Tubular Exchanger Manufacturers Association. An advantage of TEMA standards is that end customers recognize that the specifications set forth comprise industry standards that directly relate to recognized quality practices for manufacturing. Vendors who build to TEMA standards can be competitively compared because tolerances and construction methods should be very similar for a given design [2].

2.2. AES TEMA Type Heat Exchangers

Floating Head Heat Exchanger (Fig. 1). A floating head is excellent for applications where the difference in temperature between the hot and cold fluid causes unacceptable stresses in the axial direction of the shell and tubes. The floating head can move, i.e. provides the possibility to expand in the axial direction [2].

The bundle can not be pulled from the front end. For maintenance both the front and rear end head, including the backing device, must be disassembled [2].

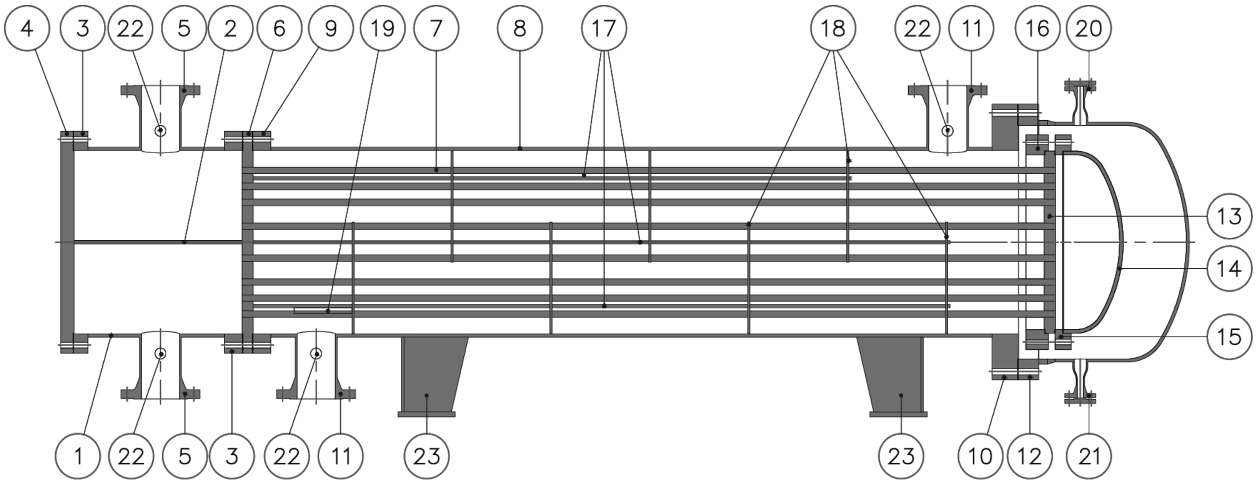

Fig. 1. *AES Tema Type*

Part Names [2]:

1.Stationary Head-Channel; 2. Pass Partition; 3.Stationary Head Flange - Channel; 4.Channel Cover; 5.Stationary Head Nozzle; 6.Stationary Tubesheet; 7.Tubes; 8.Shell; 9.Shell Flange - Stationary Head End; 10.Shell Flange - Rear Head End; 11.Shell Nozzle; 12.Shell Cover Flange; 13.Floating Tubesheet; 14.Floating Head Cover; 15.Floating Head Cover Flange; 16.Floating Head Backing Device; 17.Tierods and Spacers; 18.Transverse Baffles or Support Plates; 19.Impingement Plate; 20.Vent Connection; 21.Drain Connection; 22.Instrument Connection; 23.Support Saddle

3. INSTRUCTIONAL DESIGN

Instructional Design is a technology which incorporates known and verified learning strategies into instructional experiences which make the acquisition of knowledge and skill more efficient, effective, and appealing [3]. The process consists broadly of determining the current state and needs of the learner, defining the end goal of instruction, and creating some "intervention" to assist in the transition. The outcome of this instruction may be directly observable and scientifically measured or completely hidden and assumed [4].

3.1. Instructional Design model

There are many Instructional Design models but many are based on the ADDIE model with the five phases: analysis, design, development, implementation, and evaluation (Fig. 2).

The ADDIE model is a framework that lists generic processes that instructional designers and training developers use [5].

The steps of ADDIE are successive, yet they are flexible. One step leads to the next, but at any time the project leader can reach back into prior steps to tweak the process. The results can be a single workshop, an entire training program (orientation, certification, succession, etc.), or creative, alternative learning opportunities. A.D.D.I.E. [6]:

The analysis phase can be considered as the “Goal-Setting Stage”. This is the stage when asking questions of stakeholders is the primary task so that we can completely understand the current situation (reality), the desired situation (goals), and then to determine what the gaps are in employee knowledge, skills and attitude. The outcome of this stage is a report that summarizes these issues known as a *training needs analysis*.

The Design stage determines all goals, tools to be used to gauge performance, various tests, body, subject matter analysis, planning and resources. The end product of this stage is a *program design outline* [5].

This document would contain all the strategies for the training program, but not the content of the topic(s).

The Development stage starts the production and testing of the methodology being used in the project. In this stage, designers make use of the data collected from the two previous stages and use this information to create a program that will relay what needs to be taught to participants. If the two previous stages required planning and brainstorming, the Development stage is all about putting it into action. This phase includes three tasks namely: drafting, production and evaluation. Development thus involves creating and testing of learning outcomes [5].

The implementation phase develops procedures for training facilitators and learners. Implementation includes evaluation of the design.

The last stage of the ADDIE method is Evaluation. This is the part where the project is being subjected to meticulous final testing of the what, how, why, when of the things accomplished (or were not accomplished) of the entire project [5].

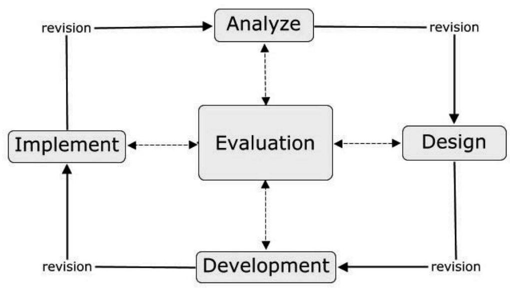

Fig. 2. ADDIE Model [5].

4. ADDITIVE MANUFACTURING (AM) TECHNOLOGIES

Additive Manufacturing (AM) technologies refer to a group of technologies that build physical objects from Computer Aided Design (CAD) data. The main difference between traditional and AM-technologies is that parts produced via AM are created by the consecutive addition of liquids, sheet or powdered materials in ultra-thin layers, instead of removing material to generate a desired shape which is common to traditional technologies such as milling or drilling [7].

AM has been around since the 1980s, and has many common names, involving rapid manufacturing, direct manufacturing, 3D-printing, rapid tooling and rapid prototyping. AM is the umbrella term for additive technologies; the terms direct manufacturing, rapid tooling and rapid prototyping refer to the application of Additive Manufacturing [7].

In addition, no matter for which purpose AM is used, many different AM-technologies are available: the foundation was laid by Stereolithography and Laser Sintering technology. Today, two main streams can be distinguished: laser-based and nozzle-based technologies [7].

4.1. STL (STereoLithography)

STL (STereoLithography) is a file format native to the stereolithography CAD software created by 3D Systems. STL is also known as Standard Tessellation Language.[8] This file format is supported by many other software packages; it is widely used for rapid prototyping and computer-aided manufacturing. STL files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common, since they are more compact [9].

An STL file describes a raw unstructured triangulated surface by the unit normal and vertices (ordered by the right-hand rule) of the triangles using a three-dimensional Cartesian coordinate system. STL coordinates must be positive numbers, there is no scale information, and the units are arbitrary [10].

4.2. SLS (Selective Laser Sintering)

Laser Sintering (SLS) uses a laser to sinter powder based materials together, layer-by-layer, to form a solid model. The system consists of a laser, part chamber, and control system [11].

The part chamber consists of a build platform, powder cartridge, and leveling roller. A thin layer of build material is spread across the platform where the laser traces a two-dimensional cross section of the part, sintering the material together. The platform then descends a layer thickness and the leveling roller pushes material from the powder cartridge across the build platform, where the next cross section is sintered to the previous. This continues until the part is completed.

Once the model is complete, it is removed from the part chamber and finished by removing any loose material and smoothing the visible surfaces [11].

4.3. Rapid prototyping for Instructional Design purposes

Many RP models have been proposed, tending to conform around the ADDIE model (analyze, design, develop, implement, and evaluate). However RP models tend to emphasize pre-design analysis, design and development and formative evaluation over summative evaluation. In addition, RP models are intended to illustrate an iterative process to design where the analysis of needs and content occurs in conjunction with the building and testing of a prototype of the instruction. For example, Yang's 1995 three-dimensional model was developed for use in computer-based courseware. This model focuses on three traditional stages: (a) analysis, (b) development, and (c) evaluation, along with a software-engineering based template for managing production activities (Yang, Moore, & Burton, 1995). Other models have been offered, tending to generally conform around the ADDIE model. Tripp and Bichelmeyer's model is as an early RP Instructional Design often cited in the RP literature. This model outlines the RP design phases as: assess needs and analyze content; set objectives; construct prototype; utilize prototype; install and maintain system. Rapid prototyping includes the "parallel processes of design and research, or construction and utilization" (Tripp & Bichelmeyer, 1990, p. 37). Front-end analysis is only intended as a starting point in the process that quickly merges into the design phase. Tripp and Bichelmeyer noted that RP approaches hinge on the use of tools and skills that offer modularity and plasticity. Modularity is defined as the ability to add, remove, or modify the instruction without severely affecting the entire design. Related to modularity, plasticity of the design means that changes to the instruction incur only minor time and cost penalties. Both of these abilities result in a flexible design that is easily modified throughout the process [12].

5. CASE STUDY

The "Hitard Engineering" has developed training process of new employees. Training process is based on a multi-phased instructional systems design according to ADDIE model.

Consistent use of this methodology, results in training solutions, thus increasing effectiveness, productivity and quality. The graphic below (Fig. 3) illustrates the major elements of the "Hitard Engineering" training approach.

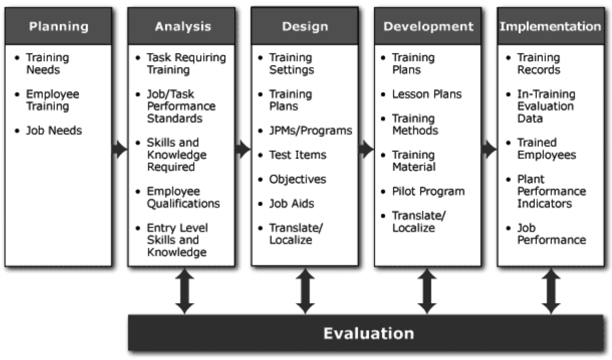

Fig. 3. *"Hitard Engineering" ADDIE Model* [13].

For the purpose of Instructional Design, company has printed 3D scale model of heat exchanger, AES type. It gives the mechanical engineer, the possibility to visualize those complex shapes not easily seen or understood on connectional drawings, and touch them to verify the shape.

5.1. 3D printer for Rapid Prototyping

For the printing 3D-models of heat exchangers, company has chosen the *RDM Makerspace* for prototyping, model making and design. Located in the same building as the Rotterdam University of Applied Science and the Albeda College at the RDM Dock, it has all kind of tools and machineries available for use: not only different types of 3D printers and 3D scanners, but also laser cutters, wood working tools, milling and welding machines [14].

RDM Makerspace has printed 3D-models of heat exchangers with *Zcorp 650 3D printer* because the capabilities of this printer is already considerable.

5.1.1 Zcorp 650 3D printer

Printing at 600x540 DPI resolution, the Zcorp 650 (Fig. 4) can 3D print the tiniest, most precise parts on a model, such as a thin wall on a mechanical prototype or a railing on an architectural model [15].

Fig. 4. *Zcorp 650 3D printer* [15].

Table 1. *Zcorp 650 Features*

Features	
Resolution	600 x 540 dpi
Minimum Feature Size	0.004 inches (0.1 mm)
Color(number of unique colors per part)	390,000 (top-of-the-line color)
Automated Setup and Self Monitoring	Y
Automated Powder Loading	Y
Powder Recycling	Y
Automatic Build Bed Clearing	Y
Fine Powder Material	Integrated
Snap-in Binder	Y
Intuitive Control Panel	Y
Vertical Build Speed	1.1 inch / hour (28 mm / hour)
Build Size	10 x 15 x 8 inches (254 x 381 x 203 mm)
Material	High performance composite
Layer Thickness	0.0035 - 0.004 inches (0.09 - 0.1 mm)
Number of Jets	1520

Table 1. *Zcorp 650 Features*

Specifications	
Number of Print Heads	5
Equipment Dimensions	188 x 74 x 145 cm (74 x 29 x 57 inches)
Equipment Weight	340 kg (750 lbs)
Power Requirements	100-240V, 15-7.5A
File Formats for Printing	STL, VRML, PLY, 3DS, ZPR
Workstation Compatibility	Windows® 7, Windows® XP Professional , Windows Vista®
CE. CSA Regulatory Compliance	Y
No Special Facility Requirements	Y

Color files need to be submitted via VRML(.wrl). If the color printer is to be used for not printing in color, then STL(.stl) should be submitted [15].

5.2. 3D scale model

The aim of this section is to show the design process, from the conception of a model to its materialization in a touchable solid model.

The scale model obtained at the end of the process, needs to be a touchable solid model, that gives the designer the general shape of the heat exchanger, in greater detail. The objective is to see how all the different parts work together.

Model of heat exchanger was chosen from the one of the project, already done by the mechanical engineer. AES type heat exchanger was chosen because of its modularity and the possibility of disassembly.

The given documentation was a construction and fabrication drawings in 2D CAD format. Construction drawings depict each part of a heat exchanger as an orthographic projection with each view containing the necessary dimensions required for assembly. The fabrication drawing depicts all the parts of the AES type heat exchanger as an orthographic projection with each view containing the necessary dimensions.

A three dimensional model needs to be created from the given information. This is the most important stage of the work, because this model will be used as reference for the next stages. It must be done on a standard format, in order to work with 3D CAD software.

Considering the limits of the built size, scale model is made up of the different parts.

The main part is the *Shell part* (Fig. 5) which consists of:

1. Shell
2. Shell Flange - Stationary Head End
3. Shell Flange - Rear Head End
4. Shell Nozzle
5. Support Saddle
6. Nameplate

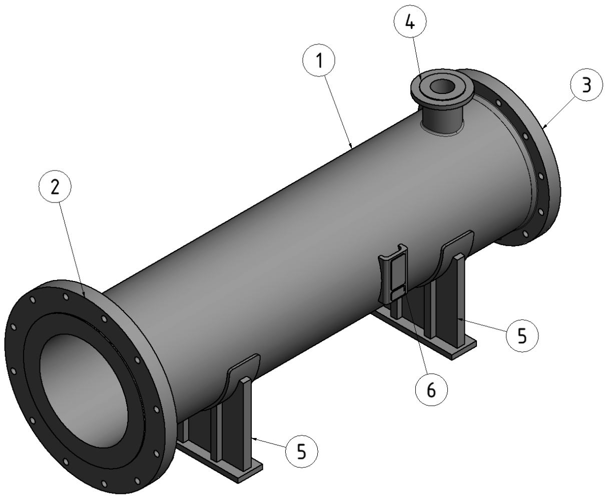

Fig. 5. *Shell part*

Considering the limits of the built size (254 x 381 x 203 mm), Shell part dimensions are on Fig.6.

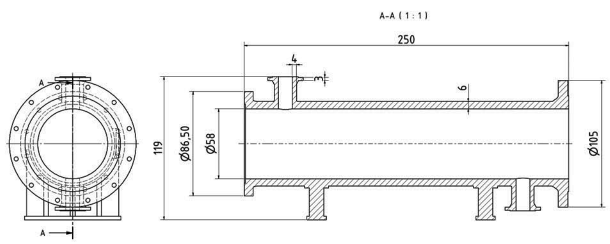

Fig. 6. *Shell part dimensions*

Second part is a *Tube Bundle* (Fig. 7) which consists of:

1. Stationary Tubesheet
2. Tubes
3. Transverse Baffles
4. Floating Tubesheet

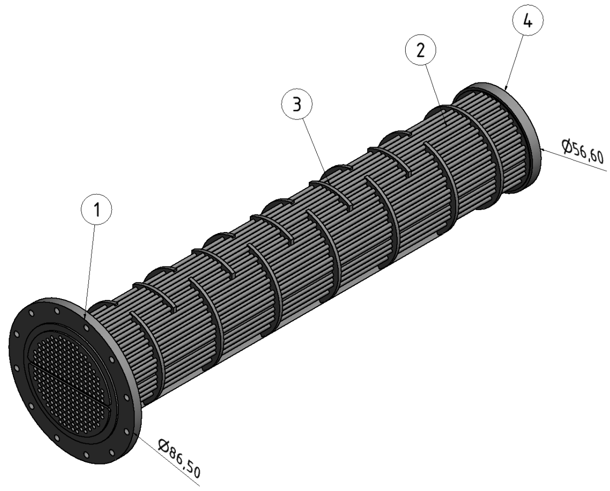

Fig. 7. *Tube Bundle*

Tube Bundle must be aligned with the *Shell part*. *Stationary Tubesheet* must have Outer Diametar (O.D.) and the Bolt Circle Diameter (B.C.D) the same size as the *Shell Flange - Rear Head End* (□86.5mm). *Floating Tubesheet* and *Transverse Baffles* must have O.D. smaller than Inner Diameter of Shell (□58mm), because they will be inside of *Shell*.

The interior of *Tube Bundle* (Fig. 8) is supposed to be empty, because material is to come out through its holes.

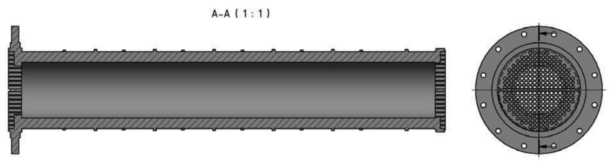

Fig. 8. *Interior of Tube Bundle*

Next parts are *Floating Head Cover* and *Floating Head Backing Device* (Fig. 9).

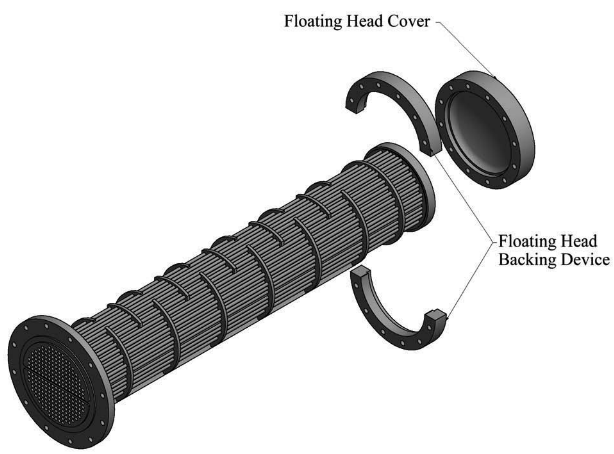

Fig. 9. *Tube Bundle*, *Floating Head Cover* and *Floating Head Backing Device*

Next part is *Stationary Head* (Fig. 10), which consists of:

1. Shell Cover Flange
2. Stationary Head - Bonnet
3. Stationary Head

Stationary Head, must be aligned with *Stationary Head End*, because of that he has dimensions listed below.

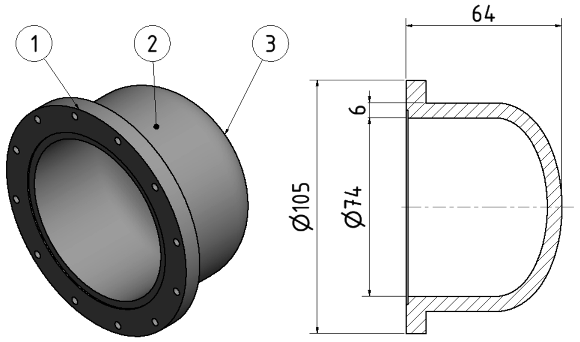

Fig. 10. *Stationary Head dimensions*

Next part was *Stationary Head-Channel,* which consists of:

1. Stationary Head-Bonnet
2. Stationary Head Flange
3. Stationary Head Nozzle
4. Pass Partition

Stationary Head-Channel, must be aligned with *Shell Flange - Rear Head End*, because of that he has dimensions listed below (Fig. 11).

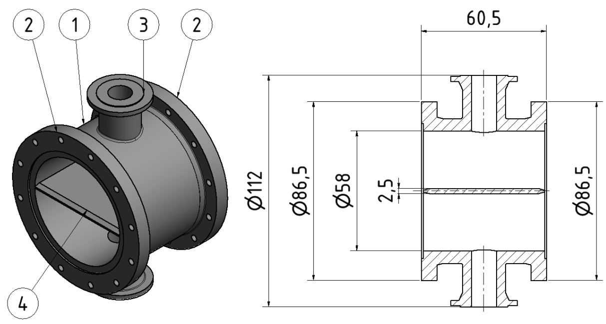

Fig. 11. *Stationary Head-Channel dimensions*

And the last, but not least part is *Channel Cover* which is aligned with *Stationary Head Flange* (Fig. 12).

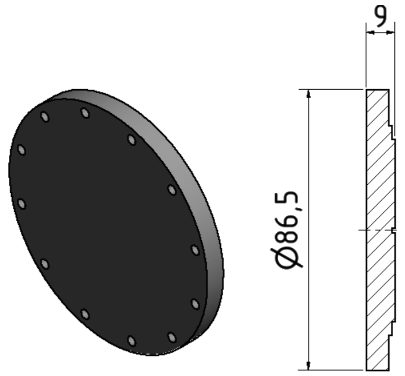

Fig. 12. *Stationary Head Flange dimensions*

Assembly of those parts is on the Figure below (Fig. 13).

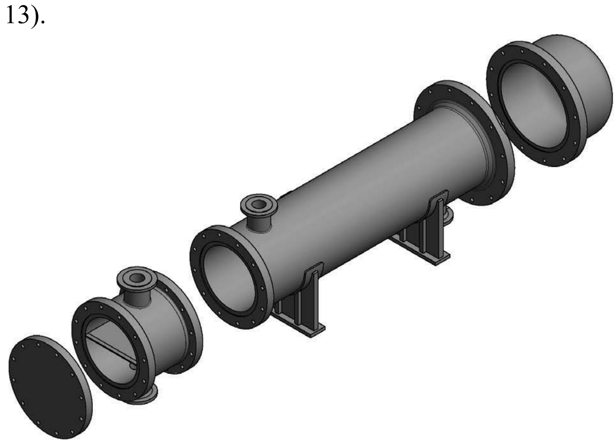

Fig. 13. *Assembly without Tube Bundle*

Section break of the entire Assembly is on the Figure below (Fig. 14).

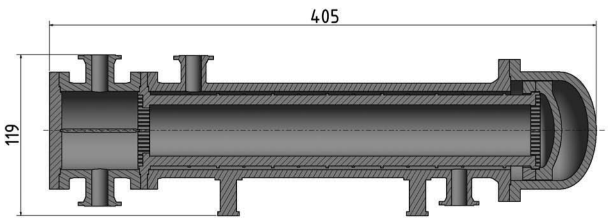

Fig. 14. *Section break of the entire Assembly*

Once the 3D solid model is completed, it should be saved in STL format (it stands from STeroLitography). This file will generate a facet model (the facets can be controlled by the different software, controlling therefore the final resolution of the model) and finally the model is sent to be built.

5.2.3. The Printing Process

The software first converts a three-dimensional design built using 3D CAD into cross-sections or slices that can be between 0.0875 - 0.1 mm thick. The printer (Zcorp 650) then prints these cross-sections one after another from the bottom of part to the top [16].

To begin the 3D printing process, the printer first spreads a layer of powder in the same thickness as the cross section to be printed. The print heads then apply a binder solution to the powder causing the powder particles to bind to one another and to the printed cross-section one level below. The feed piston comes up one layer and the build piston drops one layer. The printer then spreads a new layer of powder and repeats the process, and in a short time the entire part is printed (Fig. 15). After printing, the part is removed from the powder bed, depowdered and dried [16].

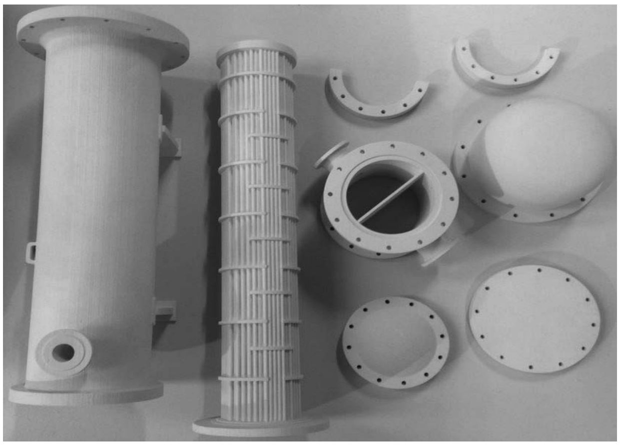

Fig. 15. *Printed parts*

The next step was to paint each part. Parts are painted with car paint. Painting was done in a home workshop.

After painting the parts, following step was to connecting the parts with the Studbolts and nuts M3 (Fig 16.).

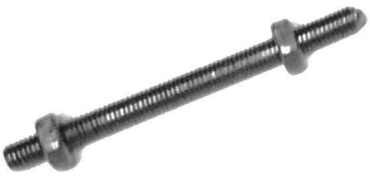

Fig. 16. *Studbolts and nuts M3*

In the picture below, we can see assembled scaled model of the heat exchanger. (Fig. 17 & Fig. 18)

Fig. 17. *Stationary Head-Channel assembled parts*

Fig. 18. *Entire assembly of the scale heat exchanger*

5.3. Case Discussion

The model of heat exchanger has been created using a 3D CAD software. When the model was finished, he was solidified, in order to generate the STL file, which was used to build the scale model by the RP system.

Rapid Prototyping physical model was built using Zcorp 650 printer using the Gypsum powder material.

After production of 3D parts, post-processing of produced parts in accordance with characteristics of building material was done.

Because of characteristics of building process, the fact that a 3D part in its untreated (raw) state contains about 10% moisture per unit weight which during a post-processing treatment evaporates and because of corrections of path of printing head during the building process (different size of printing point and printer resolutions) there are certain smaller or bigger deviations of dimensions of produced 3D parts [17].

In this Case Study, physical model of the main part (*Shell part*) has a dimensional deviation in direction of x-axis (Fig. 19). Deviations are corrected by additional treatment.

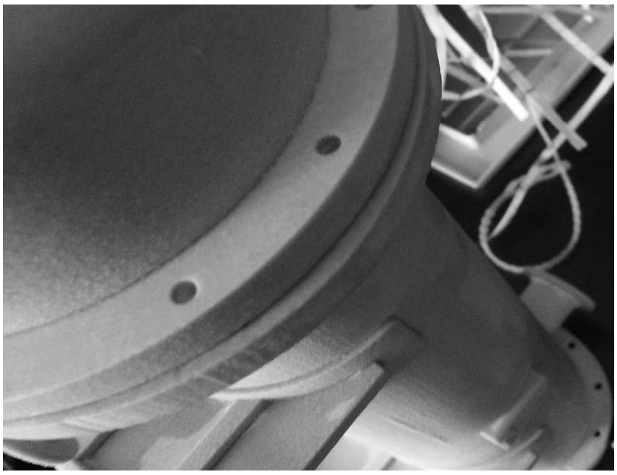

Fig. 19. *Dimensional deviation in direction of x-axis*

Besides the AES type of the heat exchanger, BEM type heat exchanger and Vertical Pressure Vessel are also modeled and printed in 3D (Fig. 20). The mean parts of this models has the same dimensional deviation in direction of x-axis.

Fig. 20. *All printed models*

Considering the above mentioned and respecting building direction and part orientation within working chamber during processing of parts it can be expected different deviations of produced parts from the dimensions defined by initial 3D CAD model. The mentioned occurrence is possible to preventive correct by adjusting the parameters of anisotropic scaling of *.stlfile of CAD model during the setup of machine [17]. Cylindrical features will be more accurate when their axis is parallel to the z-axis [16].

6. CONCLUSION

In this paper, Rapid Prototyping model is used for the purpose of Instructional Design training for new employees in the company.

Those models build by Rapid Prototyping technologies gives the mechanical engineer, the possibility to visualize those complex shapes and see how all the different parts work together. They can touch them and verify the shape.

The use of Rapid Prototyping technologies is essential in any design fields. In a few hours the model can be built easily, in a similar way as a 2D drawing is plotted [18].

In a short time, rapid prototyping will become a technology that will be used routinely by many design engineers in conjunction with the traditional existing ways of creating scale models of mechanical parts [19].

In fact, 3-D printing technology is advancing at a staggering rate. American designers are now working on 3-D printed cars, while in China and Holland, 3-D printers are building entire houses. The first 3-D printed hamburger was recently created in England, heralding the possibility of a man-made food supply [20].

Boeing, GE and other industry leaders are manufacturing state-of-the-art aerospace equipment with the new technology, while NASA, using Zero-G technology, is demonstrating how 3-D printers will one day be used in space [20].

Perhaps most dramatic are the advances being made in the medical field. Research and development of 3-D printing-based medical techniques have already saved countless lives and opened the doors to previously unimaginable possibilities in medicine [20].

7. REFERENCES

[1] Frank P. Incropera, David P. DeWitt, Theodore L. Bergman, Adrienne S. Lavine *"Fundamentals of Heat and Mass Transfer "*, John Wiley & Sons, USA, Apr. 12, 2011

[2] *Standards of the Tubular Exchanger Manufacturers Association*, Seventh edn., 1988, TEMA, Inc., 25 North Broadway, Tarrytown, New York 10591, USA.

[3] Merrill, M. D., Drake, L., Lacy, M. J., Pratt, J., & ID2_Research_Group. (1996). Reclaiming instructional design. Educational Technology, 36(5), 5-7.

[4] Mayer, Richard E. *"Cognition and instruction: Their historic meeting within educational psychology",* Journal of Educational Psychology, Vol 84(4), Dec 1992, 405-412.

[5] Ed Forest, *"The ADDIE Model: Instructional Design*", Educational Technology, January 29, 2014

[6] B. Lynn Lehman, M.Ed., *"A Proactive Approach to Employee Training & Development*", Rising Sun Consultants, White Paper, January 2007

[7] Jürgen Gausemeier, *"Thinking ahead the Future of Additive Manufacturing –Exploring the Research Landscape*", Heinz Nixdorf Institute, University of Paderborn – Paderborn 2013

[8] STL 2.0 May Replace Old, Limited File Format. Rapidtoday.com (2009-10-30)

[9] Burns, Marshall, *"Automated Fabrication: improving productivity in manufacturing*", PTR Prenrice Hall, Jul 1, 1993

[10]http://en.wikipedia.org/wiki/STL_%28file_format%29

[11]http://www.quickparts.com/LowVolumePrototypes/SLS.aspx

[12]Jenny Daugherty, Ya-Ting Teng, Edgard Cornachione, *"Rapid Prototyping Instructional Design: Revisiting the ISD Model*", University of Illinois at Urbana-Champaign and University of Sao Paulo/Brazil, 2007

[13]http://contentdevelopment.gpstrategies.com/proc.aspx

[14]http://changeyourperspective.com/insights/3d-printing-the-port/

[15] Z Corporation: ZCast® 501 Direct Metal Casting-DESIGN GUIDE

[16]http://www.zcorp-users.com/

[17]Topčić, A., Cerjaković, E., Lovrić, S., *"Analysis of dimensional deviation of parts based on ceramic produced by three dimensional printing process",* Journal of Production Engineering, Vol.17, No.1, June 2014

[18] Vaibhav A. Kakade, R.A. Kubde, *"Preliminary Study on Potential Use of Rapid Prototyping For Designing Casting Mould",* International Journal of Enhanced Research in Science Technology & Engineering, Vol. 3 Issue 4, April-2014, pp: (512-516)

[19] Dheeraj Nimawat , Mahaveer Meghvanshi, *"Using Rapid Prototyping Technology In Mechanical Scale Models*", International Journal of Engineering Research andApplications (IJERA), Vol. 2, Issue 2,Mar-Apr 2012, pp.215-219

[20] Linda Federico-O'Murchu, *"How 3-D printing will radically change the world*", May 2014 (http://www.cnbc.com)

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