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ECO - FRIENDLY CUSTOMIZED GEOPOLYMER COMPOSITE MATERIALS

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Keywords: composites, geopolymers, waste, sustainable, customization

Abstract: One of the biggest problems facing humanity in recent years is the environmental pollution from industrial and municipal waste. Global efforts are being made to address these problems on a community-wide basis. Tyres are a major problem as the amount of waste increases in proportion to the demand for new cars. It is therefore essential to develop new environmentally and economically sound methods for recycling a waste tyre. From an economic point of view, the use of waste material is irreplaceable. The aim of the present paper is to utilize waste tyre fabrics as a filler which will use as a reinforcement in a geopolymer matrix. The geopolymer Baucis L 160 (cement and activator) and fabrics with a purity of 52% were used for the manufacturing. The advantage of this material is its customized environmental, economic and social benefit for various areas of industries.

1 Introduction

The term geopolymers refers to inorganic polymeric materials which are prepared by the polycondensation reaction of basic aluminosilicate materials in a basic environment at normal temperature and pressure [1]. This reaction is referred to as geopolymerization.

Geopolymers belong to the group of mineral composite materials of unconventional composition, which are very similar to inorganic materials - zeolites.

Essentially, geopolymers are defined as calcium-free alkaline aluminosilicates most commonly prepared by alkaline activation of metakaolin with sodium or potassium hydroxide solution or water glass. The term geopolymer was first used in 1979, when this material was patented by prof. Joseph Davidovits, who described the geopolymer as a material [2].

Essentially, a geopolymer is an amorphous aluminosilicate material consisting of tetrahedral aluminium and siliceous units condensing at room temperature to form equilibrium structures in the presence of a monovalent alkali metal ion [3].

Such a material then exhibits very surprising properties, such as water solubility, non-flammability, and resistance to temperatures of about 1000 °C. their fire resistance [2,3].

The geopolymer polymer Parament®, used to repair the Los Angeles airfield, and the geopolymer polymer composite carbon / Geopolymit®, used for fire-resistant lining of the aircraft cabin, have been developed for the construction industry [1,5].

Geopolymer and carbon fibre composites have been developed for aeronautics and Formula 1 cars. These composite materials are used in thermally stressed parts of the monopost, e.g. exhaust systems [4].

On the basis of customized users or applications, our research focuses on the manufacturing of geopolymer composites for major applications, sales volume, market share according to growth rate of each Global geopolymer customized applications (Figure 1) [2].

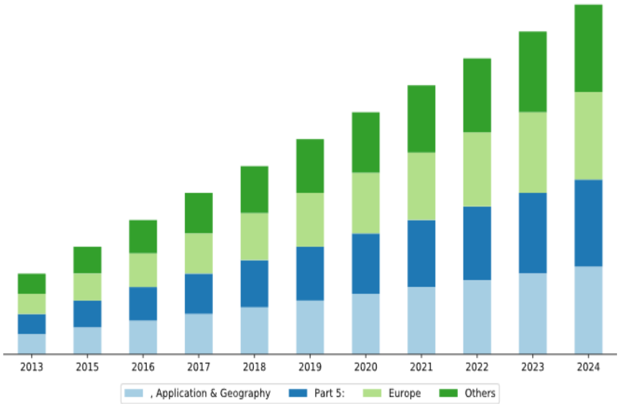

Figure 1 Global customized geopolymer applications (y.2013-2024) [2]

We presented following the key players who deal with worldwide geopolymers manufacturing and production [2]:

- PCI Augsburg GmbH (Basf),
- Schlumberger Limited,
- Wagner Global,
- ASK Chemicals,
- Milliken Infrastructure Solutions,
- INOMAT GmbH,
- W llne,
- Zeobond,
- Ecocem,
- Česke lupkové závody,
- Alchemy Geopolymer,
- Fengyuan Chemical.

The automotive industry is going through a difficult period due to customs, Brexit, economic conditions and very strict environmental legislation in Europe [3]. Nowadays, tyres are valuable source of raw material. It focuses on the emerging material from amounts collected or processes, for most materials, some percentage of the input material is lost during processing, due to removal of the rubber component, a metal fabric. Using waste tyres only for recycling itself makes no sense. Over 100 independent companies in all EU member States are recycling tyres across Europe [2,3]. There are many companies involved in collecting and processing information on the recovery or disposal of waste tyres in the world, and in Europe. One of the main organizations is ETRA (European Tyre Recycling Association), which collects information, processes, evaluates and informs the population about new possibilities for recovery and use of this commodity.

Some of the applications studied in Global Geopolymer report are:

- Automotive and Aerospace Industries,
- Building Materials,
- Transportation,
- Others.

2 Characterization of material investigation- a work methodology

2.1 Geopolymer as a matrix

The geopolymer mixture compounds of cement (Table 1) and activator Baucis L 160 has a well-defined mixing ratio, which is indicated on the packages, but also in the product materials of the mixture. The ratio for this mixture is 5 parts by weight of cement to 4 parts by weight of activator, which can be seen in Figure 2 as a final homogenization of both components.

Table 1 Chemical composition of geopolymer cement Baucis L160 [4]

Composition	Volume [%]
Na_2O	9,24
MgO	2,12
Al_2O_3	24,03
SiO_2	50,94
SiO_3	0,44
K_2O	0,61
CaO	10,08
TiO_2	0,97
FeO	0,85
Σ	99,28

By homogenization of the Baucis L 160 cement and the activator was produced a geopolymer mixture (Figure 2), which was subsequently reinforced at a percentage of 1%, 5%, 10% and 15% of the fabrics from waste tyres.

Figure 2 Homogenization of geopolymer composite material [authors own processing]

The production of one tonne of traditionally cements generates 0,55 tonnes of chemical $C0_2$ and requires an additional 0,39 tonnes of $C0_2$ in fuel emissions for baking and grinding, accounting for a total of 0,94 tonnes of

$C0_2$. Other studies reported that the cement industry emitted in 2000, on average, 0,87 kg of $C0_2$ for every kg of cement produced. In general, the cement industry contributes about 7% of the total worldwide $C0_2$ emissions [4]. This is the aim of our research and one of the most preferred advantage of used of geopolymer as a matrix by manufacturing of reinforced composites.

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2.2 Fabrics from waste tyres as a filler

Requirements for dismantling, reusing and recycling vehicles, and for their components, should be integrated into the design and manufacture of new vehicles. This Directive lays down measures and objectives where, firstly, the prevention of vehicle waste, as well as the reuse, recycling and other forms of recovery of End-Of-Life components and their components, are reduced to reduce waste disposal [2,3]. Last but not least, to improve environmental protection by all economic operators involved in the life cycle of vehicles and in particular operators directly involved in the processing of end-of-life vehicles. Figure 3 represents sample of fabrics from waste tyres after vibrating screens separation. The purity is 52%.

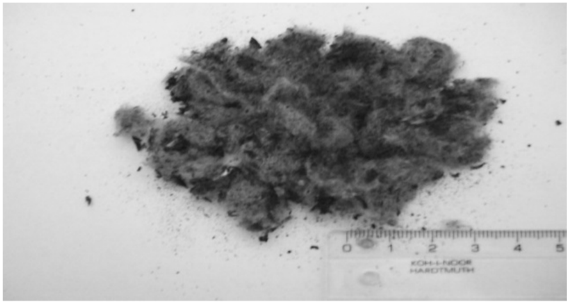

Figure 3 Fabrics from waste tyres after vibrating screens separation [authors own processing]

The main function of fibres in tyres is to provide the performance stability of the car through the required operating conditions. They represent special design and operating categories for a given car [3,5]. Ensuring high performance is one of many examples. The fabrics composition was mainly derived from the presence of cellulose and polyamide PA 6, also polyamide PA 6.6 for medium performance tyres. Polyesterterephthalate (PET), polyethyleneenaphthalate (PEN), and aramid are referred to as high performance tyre fibres [6]. They are also used to make commercial truck tyres [7]. The various national end-of-life vehicle measures should be harmonized to minimize the environmental impact of end-of-life vehicles, thus contributing to protecting, preserving and improving the quality of the environment and saving energy and, consequently, ensuring the smooth functioning of the internal market and avoid restricting competition in the EU community.

After mechanical testing/bending stress (Table 2, Figure 5) at maximal bending load we obtained results for 4 tested samples for each % of filler were prepared 4 samples. Geopolymer composite material reinforced by 10% of waste tyre fabrics has value of 5,747MPa of bending stress by maximal bending force F_{max} 2068,46 N. For comparison, the 15% of filler has value of 4,000 MPa by 1512,49 N of maximal bending load. This difference is due to homogenization of geopolymer composites material.

3 Results and discussion

After 28 days of geopolymer setting, we tested the geopolymer composite material and determined the strength characteristics, namely strain at break and elongation at break. Figure 4 shows a final sample of geopolymer composite material.

Figure 4 Geopolymer reinforced with fabrics from waste tyres [authors own processing]

Table 2 Bending Stress of tested geopolymer composites materials [authors own processing]

	F_{max} (N)	A_{max} (mm)	Bending stress at maximal Bending load (MPa)
Red line	1982.56	0.56	5.119
Brown line	1906.58	0.89	4.745
Green line	2068.46	0.73	5.747
Blue line	1512.49	0.67	4.000
Irregularity coefficient	13.15928	11.00214	14.89615
Standard deviation	245.75260	0.07365	0.73031
Median	1867.52	0.67	4.903

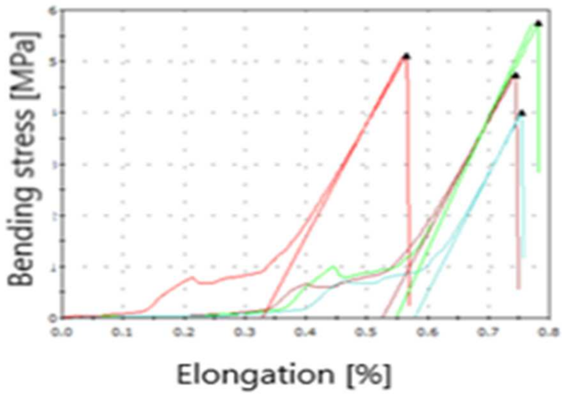

Figure 5 Dependence of elongation on bending stress [authors own processing]

Legend:
Red line- 1% fabrics from waste tyres,
Brown line- 5% fabrics from waste tyres,
Green line-10% fabrics from waste tyres,
Blue line- 15% fabrics from waste tyres.

Based on the results we can say that the 10% proportion of waste textiles has the highest strength values. From a technological-processing point of view, it is important to say that in the production of geopolymer composite material we the possibility of reducing environmentally undesirable impacts on the environment, where we evaluated 3 key areas, which are:

- Production,
- Customization,
- Product disposal options.

During production it is necessary to analyse:

- Input raw materials,
- Energy,
- Human resource.

In customization, it is a complex view of:

- Output products - finished products,
- Customers,

Nowadays, waste is a substantial part of the whole product life cycle, where we focus on the possibility of:

- Landfilling,
- combustion,
- re-use materials,
- recycling.

4 Conclusion

Geopolymer composites materials have high resistance to aggressive environment of sulphate and chloride solutions. They are better resistant to acidic aggressive environments and are highly resistant to alternating freezing and thawing. The penetration of Cl^- and SO_4^{2-}ions into the mass of geopolymer materials is significantly lower than that of Portland cement masses. Geopolymers resist exposure to high temperatures up to 600 - 800 °C, where residual strengths are greater than in Portland cements [8,10].

The final properties of geopolymer composite materials are significantly influenced by the temperature and duration of geopolymerization, the starting material (chemical composition, particle size, CaO content), Si: Al ratio, activation solution concentration and composition, pH, water content and solidification time [9,10].

Geopolymer composite materials reinforced with fabrics from waste tyre have excellent mechanical strength due to a high degree of polycondensation, high durability (geopolymer concrete or mortar resists weathering without significant changes), unique heat-insulating properties, are easily recyclable, are resistant to heavy metals.

Based on the achieved results, we conclude that geopolymers can be considered as prospective materials meeting demanding technical as well as ecological requirements.

They are materials capable of competing technically with Portland cements and ecologically superior to them.

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THE POSSIBILITY OF USING PCM SLURRY AS A CIRCULATING MEDIUM IN A HEATING SYSTEM – MODEL TESTS

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Keywords: numerical model, PCM, slurry, CFD

Abstract: The aim of the article is to develop a numerical model in order to compare the classic heating system with a heating system where PCM slurry constitutes the heat-transfer medium. Physical parameters such as PCM slurry specific heat, viscosity and thermal conduction are required in order to generate the numerical model. PCM producers do not possess the required data, so the performance of specialist tests in outside institutions is necessary in order to obtain these values. PCM materials are substances with high heat of fusion values. During fusion or solidification at a specific temperature, they accumulate or release high amounts of energy. The numerical model consists of two parts that make it possible to compare various heat-transfer media (water and PCM slurry). The model tests encompass the simulation of parameters and their variations for a system utilising water and utilising the PCM slurry at their various concentrations. The tested parameters are variations of slurry temperature at the heat exchanger outlet, depending on the PCM concentration in the slurry. Among the many testing methods, it was decided to analyse the presented solution using the computational fluid dynamics (CFD) method. Analysed test subject numerical solution geometry and discretisation area were discussed, as well as numerical model assumptions and parameter values for the developed PCM slurries.

1 Introduction

In last decade most recent researchers are focused on improve energy efficiency with use of latent heat thermal storage materials such as phase change materials (PCM) [1,2]. This interest was derived growth of need in materials having the ability to thermal energy storage. PCM are characterized by a number of parameters which are interrelated such as: density, specific heat, thermal conductivity, which increase capacity to absorption and emission of large amount of heat during physical state change process due to higher heat density [6]. Higher heat density directly determines PCM ability to heat thermal storage [3-5,7].

The analysed research problem comes down to describe the possibility to use phase-change materials (PCM) as substances improving the efficiency of a selected heat exchanger, based on numerical simulations. Positive results of numerical calculations may contribute to a decrease of the heat exchanger surfaces as well as a decrease in the amount of fuel supplied to the heat source, which may translate into profits for heat storage system users, generally to minimize power consumption in heating system basing on water [8-12].

It was decided to conduct the numerical analysis using the computational fluid dynamics (CFD) method in the Ansys-Fluent program, based on the numerical model simulating the transfer process of the PCM slurry at a volume reflecting the fluid geometry. Ansys-Fluent is an extraordinarily efficient and modern tool that minimises the expenditure required to study a subject during the initial stage of a project, while simultaneously enabling the control and verification of many variants of possible variables. The obtained numerical solution made it possible to compare a classic heating system with a heating system where PCM slurry constituted the heat-transfer medium. In order to generate a numerical model, laboratory tests were conducted to determine the slurry specific heat, viscosity and thermal conduction at various PCM concentrations [18-19].

The numerical model data were obtained from literature, practical knowledge and substance physical property tabular data as well as from conducted tests of phase-change substance physical properties (PCM slurry specific heat, viscosity and thermal conduction).

The developed numerical model was divided into two parts enabling the prediction and comparison of various heat-transfer media. The first part encompassed the simulation of parameters and their variations for a standard system utilising water. Whereas the second part simulated the same parameters and their variations for a system utilising PCM slurry at various concentrations. Variations of slurry temperature at the heat exchanger outlet constituted the tested parameters [20-21].

2 Material and method

2.1 Laboratory test

Phase-change materials (PCM) are active phase-change compounds encapsulated within an impermeable polymer membrane in the form of a capsule with a size of 5-50 µm. The aim of such action is to completely separate and secure them from environmental influence. Under specific ambient temperature conditions, they accumulate or release large amounts of energy at a nearly constant temperature corresponding to the phase transition temperature of the phase-change material (PCM) [2-5].

Mixtures in the form of dispersions based on water with no mineral salts with the addition of a phase-change material (PCM) in the amount of 10%, 20% and 30% were prepared for realisation purposes. The PCM slurry preparation stages were presented schematically in Figure 1.

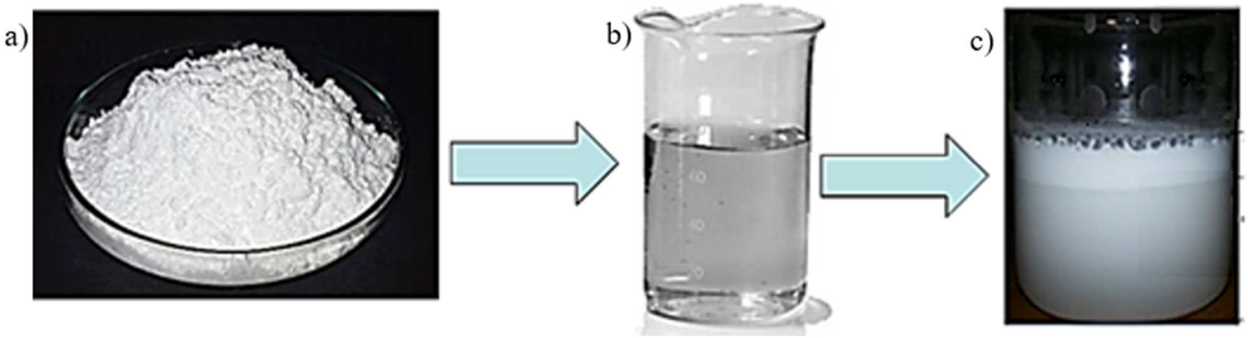

Figure 1 PCM slurry preparation stages: a)- PCM, b)- distilled water, c)- PCM slurry [2,6]

Individual PCM slurry samples underwent testing under laboratory conditions in order to determine the average values of such parameters as:

- specific heat using a Netzsch STA 409 PC Luxx thermal analysis device (Figure 2), simultaneous thermogravimetric and calorimetric analyses from 20°C into the temperature range of 1650°C,

Figure 2 STA 409 PC Luxx Simultaneous thermal analyser [13]

- thermal diffusion using a Netzsch LFA 457 analyser (Figure 3), allows measurements from -125°C to 1100°C with measuring range 0.01 mm2s-1 to 1000 mm2s-1 for thermal diffusivity and measuring range 0.1 Wm-1K-1 to 2000 Wm-1K-1 for thermal conductivity,

Figure 3 Netzsch LFA 457 analyser [14]

- dynamic viscosity using a TA Instruments AR2000ex rheometer (Figure 4).

Figure 4 TA Instruments AR2000ex rheometer analyser [15]

The defined physical property values directly determine the application of a heat-transfer medium in a heating system. The obtained investigated parameter values constituted the input data for the developed numerical model.

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2.1.1 Result

In Figures below was shown the results of laboratory measurements of PCM slurry parameters depending on temperature changes such as:

- influence of temperature changes on the PCM slurry viscosity shown in Figure 5,
- influence of temperature changes on the PCM slurry thermal diffusivity shown in Figure 6,
- influence of temperature changes on the PCM slurry specific heat shown in Figure 7.

The obtained results were subjected to regression analysis with the intention of determining the equation reflecting the variability of the tested PCM slurry parameters. An effect of the activity's equations describing variability of parameters of PCM slurry such as specific heat, viscosity and thermal diffusivity in the range of temperature changes from 20ºC to 85ºC in the following form:

a) for 10% PCM slurry:
   - dynamic viscosity correlation was obtained in form of $y = 0.0001x + 0.0214$,
   - thermal diffusivity correlation was obtained in form of $y = 3e^{-6}x^5 – 0.0009x^4 + 0.1132x^3 – 7.3426x^2 + 236.17x – 3010.9$,
   - specific heat correlation was obtained in form of $y = 5e^{-5}x^6 – 0.0133x^5 + 1.5989x^4 - 101x^3 + 3536.5x^2 - 64973x + 491153$ for T< 71.2ºC and $y = 0.0007x^6 - 0{,}344x^5 + 70.756x^4 – 7758.8x^3 + 478354x^2 - 2e^7x + 2e^8$ for T ≥ 71.2ºC.

b) for 20% PCM slurry:
   - dynamic viscosity correlation was obtained in form of $y = 0.0009x + 0.1191$,
   - thermal diffusivity correlation was obtained in form of $y = 5e^{-7}x^5 – 0.0002x^4 + 0.0256x^3 – 1.754x^2 + 59.071x – 781.62$,
   - specific heat correlation was obtained in form of $y = 0.0001x^6 - 0{,}0389x^5 + 4.6538x^4 – 292.89x^3 + 10227x^2 - 187780x + 1e^6$ for T< 71.2ºC and $y = 0.0037x^6 – 1.8287x^5 + 373.7x^4 - 40704x^3 + 2e^6x^2 – 8e^7x + 1e^9$ for T ≥ 71.2ºC.

c) for 30% PCM slurry:
   - dynamic viscosity correlation was obtained in form of $y = 0.003x + 0.4368$,
   - thermal diffusivity correlation was obtained in form of $y = -4e^{-6}x^5 + 0.0014x^4 – 0.1727x^3 + 10.939x^2 – 343.2x + 4268.2$,
   - specific heat correlation was obtained in form of $y = 0.0002x^6 – 0.0464x^5 + 5.5057x^4 – 343.14x^3 + 11852x^2 - 215037x + 2e^6$ for T< 71.2ºC and $y = 0.0082x^6 – 3.9909x^5 + 812.11x^4 - 88095x^3 + 5e^6x^2 – 2e^8x + 2e^9$ for T ≥ 71.2ºC.

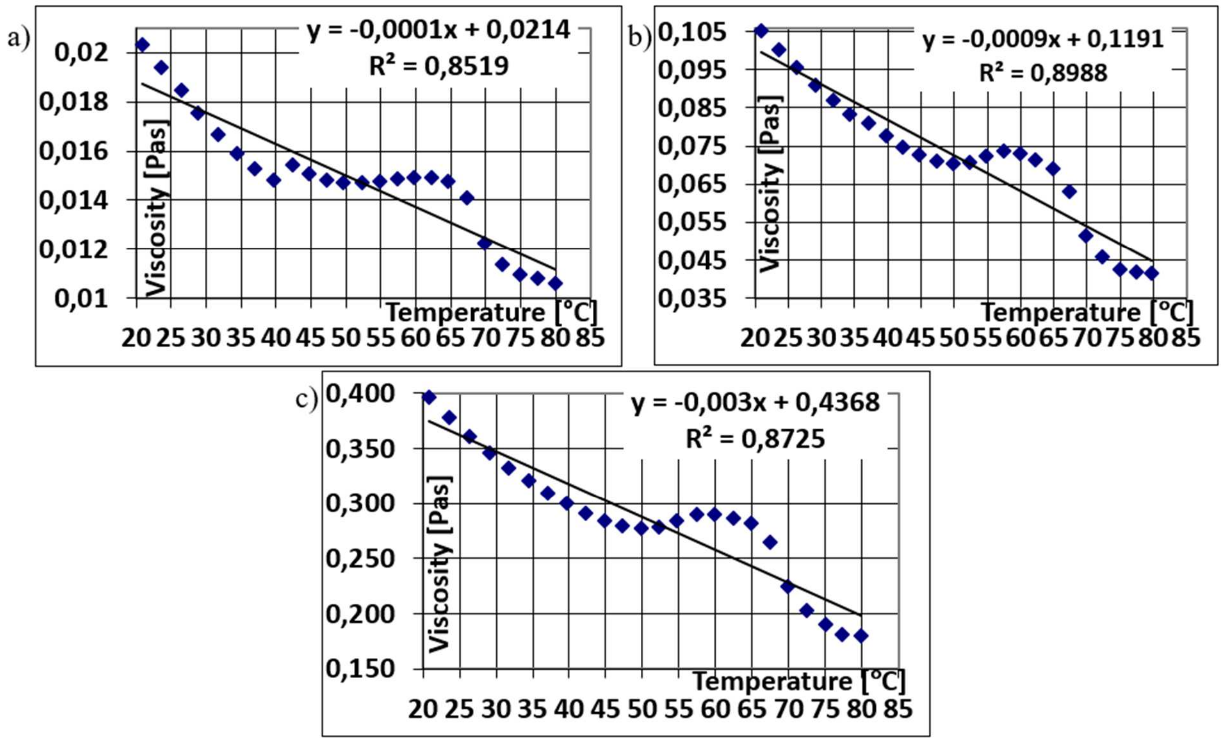

Figure 5 Influence of temperature on the dynamic viscosity of PCM slurry: a) – 10% PCM, b) – 20% PCM, c) – 30% PCM

When the ambient temperature of PCM slurry increases, the dynamic viscosity of the mixture decreases can be observed. Additionally, it can be observed that with increasing the concentration of PCM in the mixture, the dynamic viscosity of the PCM slurry a significant growth.

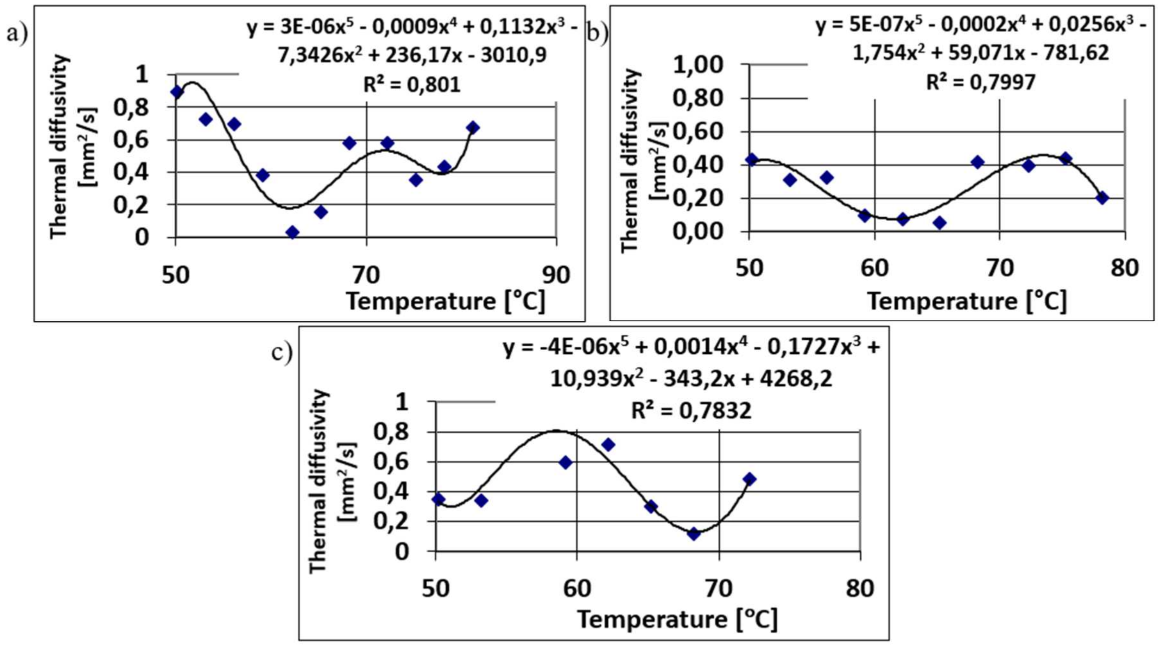

Figure 6 Influence of temperature on the thermal diffusivity of PCM slurry: a) – 10% PCM, b) – 20% PCM, c) – 30% PCM

When the ambient temperature of PCM slurry increases, the thermal diffusivity of the mixture decreases up to 65°C, but after that increases relatively quickly. Additionally, it can be observed that with increasing the concentration of PCM in the mixture, the dynamic viscosity of the PCM slurry a significant decrease.

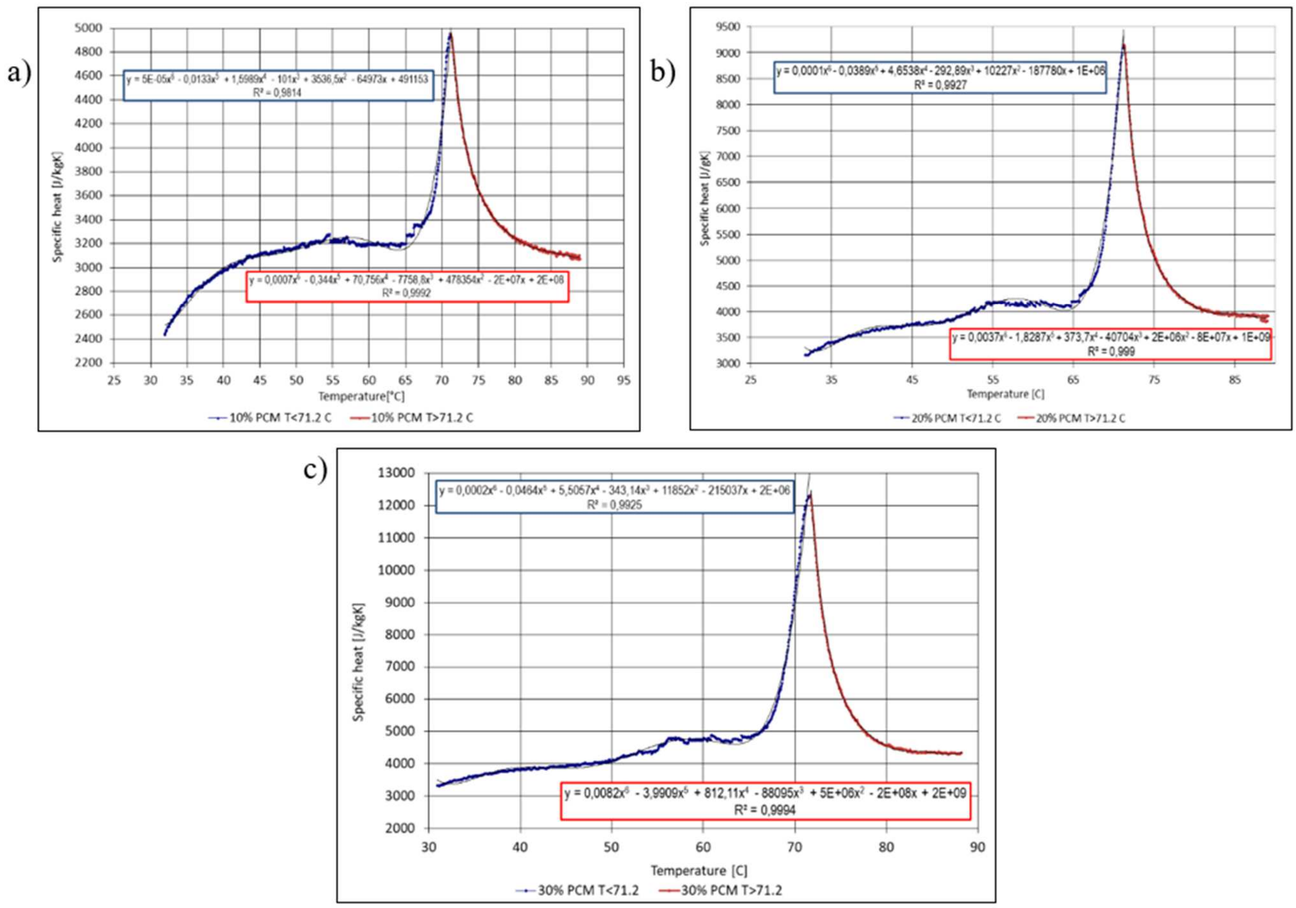

Figure 7 Influence of temperature on the specific heat of PCM slurry: a) – 10% PCM, b) – 20% PCM, c) – 30% PCM

When the ambient temperature of PCM slurry increases, the specific heat of the mixture decreases up to 73°C, but after that decreases relatively quickly. Additionally, it can be observed that with increasing the concentration of PCM in the mixture, the specific heat of the PCM slurry a significant increase.

2.2 Numerical model

The numerical analysis encompassed medium circulation in a heating system (central heating) where the thermal energy required to acquire the necessary heat-transfer medium temperature was obtained as a result of solid fuel combustion in a heating boiler. The heated medium is supplied via pump to a double-wall plate heat exchanger, where the heat is transferred to the air flowing around the external surfaces of the heat exchanger. The cooled medium is drained to the boiler, where it is heated again, closing the circulation of the medium in the system. Figure 8 presents a diagram of the examined central heating system.

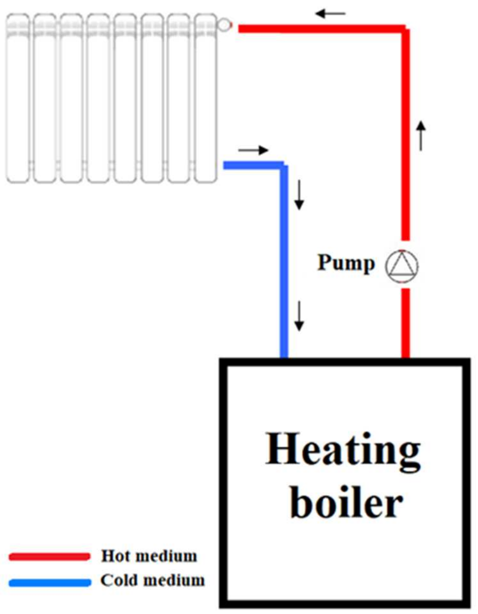

Figure 8 Analysed heating system

2.2.1 Geometry

Test subject geometry consists of a spatial model of fluid volume isolated from the developed geometry of a heat exchanger constructed from a 1.25 mm-thick steel sheet and with dimensions of 500 mm x 500 mm, which constitutes the image of a real double-wall plate heat exchanger. The distance between plates is 20 mm. Figure 9 presents the developed heat exchanger spatial model that constitutes the subject of model testing.

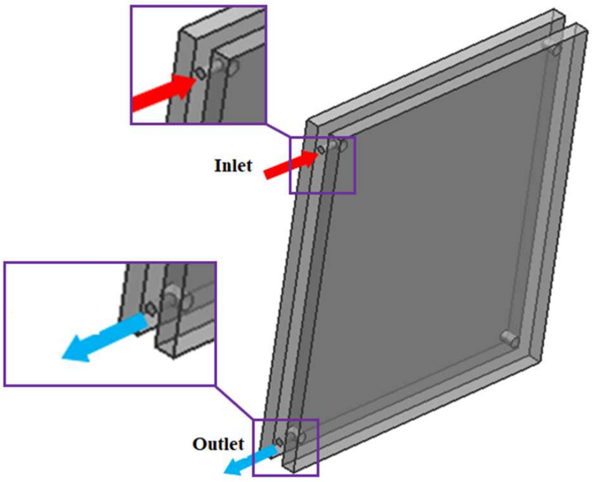

Figure 9 Double-wall heat exchanger spatial model

2.2.2 Numerical grid

The numerical solution discretisation area consists of the fluid volume isolated from the double-wall plate heat exchanger geometry, generated using 68079 simple elements mutually connected with 14578 nodes. Figure 10 presents the discretisation area of the analysed heat exchanger numerical model. The numerical grid was exported to the Ansys-Fluent program.

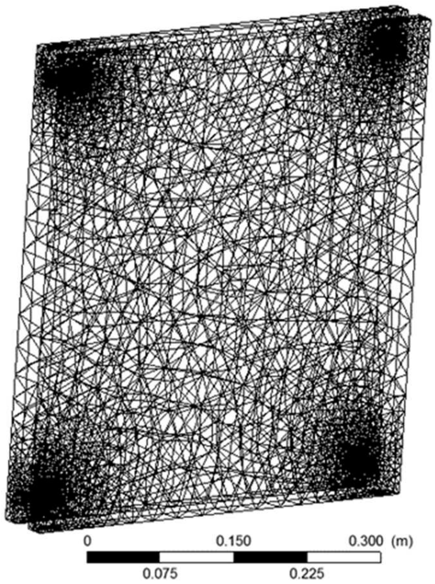

Figure 10 Heat exchanger numerical grid

2.3 Numerical model assumptions

The CFD method consists in obtaining a solution of a coupled system of differential equations defining the conservation of mass, momentum and energy principles in the following forms [1]:

- conservation of mass equation:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{v}) = S_m \tag{1}$$

where:

t time, s

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ρ fluid density, $kg\ m^{-3}$
$\vec{v}$ fluid element velocity vector, $m\ s^{-1}$
S_m source term related to mass transfer, $kg\ m^{-3}\ s^{-1}$

- conservation of momentum equation [1]:

$$\frac{\partial}{\partial t}(\rho\vec{v})+\nabla\cdot(\rho\vec{v}\vec{v})=-\nabla p+\nabla\cdot(\tilde{\tau})+\rho\vec{g}+\vec{F} \quad (2)$$

where:
$\bar{v}$ fluid element velocity vector, $m\ s^{-1}$
p fluid pressure, Pa
μ fluid dynamic viscosity, $Pa\ s$
$\vec{g}$ gravitational acceleration, $m\ s^{-2}$
$\tilde{\tau}$ stress tensor, $kg\ m^{-3}\ s^{-1}$
$\vec{F}$ vector of internal forces exerted on the body in the cross-section, N

- conservation of energy equation [1]:

$$\frac{\partial}{\partial t}(\rho E)+\nabla(\vec{v}(\rho E+p))=\nabla\left(k_{eff}\nabla T-\sum h_j\vec{J}_j+(\tilde{\tau}_{eff}\cdot\vec{v})\right)+S_h \quad (3)$$

where:
t time, s
$\vec{v}$ fluid element velocity vector, $m\ s^{-1}$
h enthalpy, $J\ kg^{-1}$
T fluid temperature gradient, K
S_h source term related to energy transfer, $J\ m^{-3}$
$\tilde{\tau}_{eff}$ stress tensor, $kg\ m^{-3}\ s^{-1}$
p fluid pressure, Pa
ρ fluid density, $kg\ m^{-3}$
k_{eff} effective conductivity coefficient, $W\ m^{-1}\ K^{-1}$

The influence of disturbances occurring during the heat-transfer medium transfer process as a result of energy loss due to friction against the walls has been described using a turbulence model *k-ε*. The solution obtainment process is based on identifying the turbulent viscosity value μ_t using the eddy kinetic energy k and dissipation speed ε. The turbulent viscosity model μ_t is described using the following equation [1]:

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon} \quad (5)$$

where:
k velocity fluctuation (turbulent) kinetic energy, $m^2\ s^{-2}$
ε turbulent kinetic energy dissipation speed, $m^2\ s^{-3}$
μ_t eddy viscosity, $Pa\ s$
C_μ empirical constant, Cμ=0.09
ρ fluid density, $kg\ m^{-3}$

Fluid transport equations for turbulent kinetic energy ***k*** and dissipation ***ε*** in terms of CFD methods are described using the following relationships [1]:

- for turbulent kinetic energy:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k v_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (6)$$

where:
k velocity fluctuation (turbulent) kinetic energy, $m^2\ s^{-2}$
V fluid element velocity vector, $m\ s^{-1}$
t time, s
μ_t eddy viscosity, $Pa\ s$
σ_k turbulent Prandtl number, $\sigma_k = 1.0$
P local vorticity fluctuation production,
ε turbulent kinetic energy dissipation speed, $m^2\ s^{-3}$
ρ fluid density, $kg\ m^{-3}$
S_k source term, $kg\ m^{-3}\ s^{-1}$

- for turbulent dissipation rate [1]:

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon v_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(Gk+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \quad (7)$$

where:
k velocity fluctuation (turbulent) kinetic energy, $m^2\ s^{-2}$
$\bar{u}$ fluid element velocity vector, $m\ s^{-1}$
t time, s
μ_t eddy viscosity, $Pa\ s$
σ_ε turbulent Prandtl number, $\sigma_\varepsilon = 1.3$
ε turbulent kinetic energy dissipation speed, $m^2\ s^{-3}$
$C_{1\varepsilon}$ empirical constant, $C_{1\varepsilon}$=1.44
$C_{2\varepsilon}$ empirical constant, $C_{2\varepsilon}$=1.92

PCM slurry density variation value has been defined with the following relationship:

$$\frac{d\rho_{zawPCM}}{dt}=\rho_w(1+\frac{dX}{dt}) \quad (8)$$

where:
X PCM material participation in the slurry,
ϱ_{zawPCM} PCM slurry density, $kg\ m^{-3}$
ϱ_w heat-transfer medium density, $kg\ m^{-3}$

The following local numerical model solution uniqueness conditions were assumed:
- initial medium temperature – 300 K (26.9°C),
- medium temperature at inlet - 348 K (≈75°C),
- specific heat c_p of PCM slurry:
  - for 10% PCM – c_p= 5e^{-5}T^6 – 0.0133T^5 + 1.5989T^4 – 101T^3 + 3536.5T^2 – 64973T + 491153 [J/kgK] for T< 71.2°C and c_p = 0.0007T^6 - 0,344T^5 + 70.756T^4 – 7758.8T^3 + 478354T^2 - 2e^{7}T + 2e^8 [J/kgK] for T ≥ 71.2°C,
  - for 20% PCM – c_p = 0.0001x^6 - 0,0389T^5 + 4.6538T^4 – 292.89T^3 + 10227T^2 – 187780T + 1e^6 [J/kgK] for T< 71.2°C and c_p = 0.0037T^6 – 1.8287T^5 + 373.7T^4 – 40704T^3 + 2e^{6}T^2 – 8e^{7}T + 1e^9 [J/kgK] for T ≥ 71.2°C,

- for 30% PCM – $c_p = 0,0002T^6 - 0,0464T^5 + 5,5057T^4 - 343,14T^3 + 11852T^2 - 215037T + 2e^6$ [J/kgK] for T< 71.2°C and $c_p = 0,0082T^6 - 3,9909T^5 + 812,11T^4 - 88095T^3 + 5e^6T^2 - 2e^8T + 2e^9$ [J/kgK] for T ≥ 71.2°C,

- thermal diffusivity α of PCM slurry:
  - for 10% PCM – $\alpha = 3e^{-6}x^5 - 0.0009\cdot T^4 + 0.1132\cdot T^3 - 7.3426\cdot T^2 + 236.17\cdot T - 3010.9$ [m²/s],
  - for 20% PCM - $\alpha = 2.5e^{-7}\cdot T^5 - 0.0002\cdot T^4 + 0.0256\cdot T^3 - 1.754\cdot T^2 + 59.071\cdot T - 781.62$ [m²/s],
  - for 30% PCM - $\alpha = -4e^{-6}\cdot T^5 + 0.0014\cdot T^4 - 0.1727\cdot T^3 + 10.939\cdot T^2 - 343.2\cdot T + 4268.2$ [m²/s],
- dynamic viscosity of PCM slurry:
  - for 10% PCM – $\mu = 0.0001\cdot T + 0.0214$ [Pa·s],
  - for 20% PCM - $\mu = 0.0009\cdot T + 0.1191$ [Pa·s],
  - for 30% PCM - $\mu = 0.003\cdot T + 0.4368$ [Pa·s],
- volumetric fluid flow rate – 1.2 [m³/h],
- specific heat c_p of water - 4182 [J/kg K],
- thermal conductivity of water - 0.6 [W/mK],
- dynamic viscosity of water - 0.001003 [Pa·s],

The following global settings were considered in the Ansys-Fluent program:
- pressure - 10 [bar],
- convective heat-transfer coefficient for air - 10 [W/m²K],
- time scale - 3600 seconds.

3 Result

Figure 11 presents the heat-transfer medium temperature variation distribution (water and PCM slurry) by measuring the value of the investigated parameter at the model heat exchanger outlet.

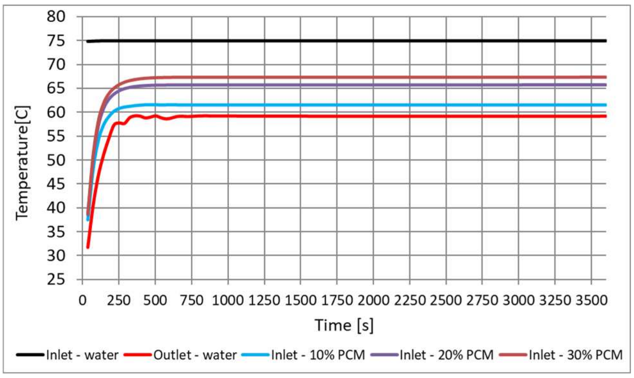

Figure 11 Changes of temperature at the outlet of heat exchanger depending on PCM concentration in the heat-transfer medium

The conducted model test results show that the obtained water temperature value at the outlet was 59.14°C. For a 10% PCM solution, the registered temperature value was at a level of 61.51°C, whereas the medium temperature for a 20% PCM water solution was 65.72°C, and 67.36°C for a 30% PCM concentration. The investigated parameter values, which constitute a numerical model solution of the PCM slurry transfer process in a model heat exchanger, have been compiled in Table 1.

Table 1 The temperature variation values (water and PCM slurry) in time interval of 3600 seconds

No.	Time [s]	Outlet - water	Outlet - 10% PCM	Outlet - 20% PCM	Outlet - 30% PCM
		Temperature [°C]	Temperature [°C]	Temperature [°C]	Temperature [°C]
1	36	31.79	37.43	38.55	38.77
2	72	40.42	47.9	50.06	50.84
3	108	46.73	54.04	57.1	58.11
4	144	51.06	57.29	60.75	61.88
5	180	54.47	59.06	62.69	63.89
6	216	57.32	60.19	63.82	65.08
7	252	57.74	60.79	64.51	65.83
8	288	57.64	61.07	64.94	66.32
9	324	58.85	61.21	65.22	66.66
10	360	59.23	61.38	65.39	66.89
11	396	59.17	61.47	65.51	67.04
12	432	58.78	61.54	65.58	67.15
13	468	58.97	61.54	65.63	67.22
14	504	59.21	61.53	65.67	67.27
15	540	58.82	61.52	65.69	67.3
16	576	58.59	61.52	65.7	67.32

17	612	58.78	61.53	65.71	67.33
18	648	59.08	61.52	65.72	67.34
19	684	59.14	61.52	65.72	67.35
20	720	59.09	61.52	65.72	67.35
21	756	59.14	61.51	65.72	67.36
22	792	59.19	61.51	65.72	67.36
23	828	59.21	61.51	65.72	67.36
24	864	59.22	61.51	65.72	67.36
25	900	59.21	61.51	65.72	67.36
26	936	59.19	61.51	65.72	67.36
27	972	59.18	61.51	65.72	67.36
28	1008	59.19	61.51	65.72	67.36
29	1044	59.19	61.51	65.72	67.36
30	1080	59.17	61.51	65.72	67.36
31	1116	59.16	61.51	65.72	67.36
32	1152	59.17	61.51	65.72	67.36
33	1188	59.17	61.51	65.72	67.36
34	1224	59.16	61.51	65.72	67.36
35	1260	59.16	61.51	65.72	67.36
36	1296	59.16	61.51	65.72	67.36
37	1332	59.16	61.51	65.72	67.36
38	1368	59.15	61.51	65.72	67.36
39	1404	59.15	61.51	65.72	67.36
40	1440	59.16	61.51	65.72	67.36
41	1476	59.15	61.51	65.72	67.36
42	1512	59.15	61.51	65.72	67.36
43	1548	59.15	61.51	65.72	67.36
44	1584	59.14	61.51	65.73	67.36
45	1620	59.14	61.51	65.73	67.36
46	1656	59.14	61.51	65.73	67.36
47	1692	59.14	61.51	65.73	67.36
48	1728	59.14	61.51	65.73	67.36
49	1764	59.14	61.51	65.73	67.36
50	1800	59.14	61.51	65.73	67.36
51	1836	59.14	61.51	65.73	67.36
52	1872	59.14	61.51	65.73	67.36
53	1908	59.14	61.51	65.73	67.36
54	1944	59.14	61.51	65.73	67.36
55	1980	59.14	61.51	65.73	67.36
56	2016	59.14	61.51	65.73	67.36
57	2052	59.14	61.51	65.73	67.36
58	2088	59.14	61.51	65.73	67.36
…	……	……	……	……	……
100	3600	59.15	61.51	65.73	67.36

Additionally, figures 12-15 present the thermal field variation distributions on the heat exchanger surface, where the utilised heat-transfer media were water (Figure 12) and slurries constituting 10% (Figure 13), 20% (Figure 14) and 30% (Figure 15) PCM dispersions.

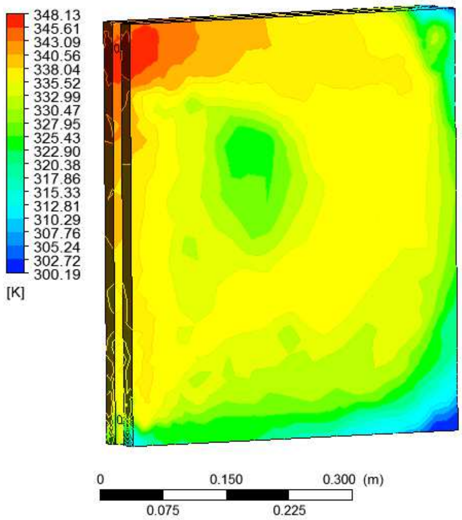

Figure 12 Water heat-transfer medium thermal field variation distribution after 3600 seconds

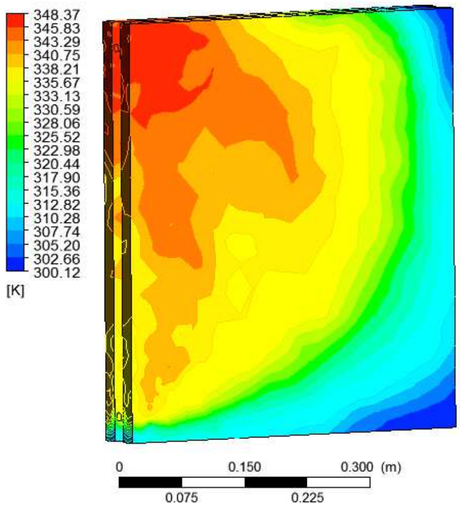

Figure 13 10% PCM slurry thermal field variation distribution after 3600 seconds

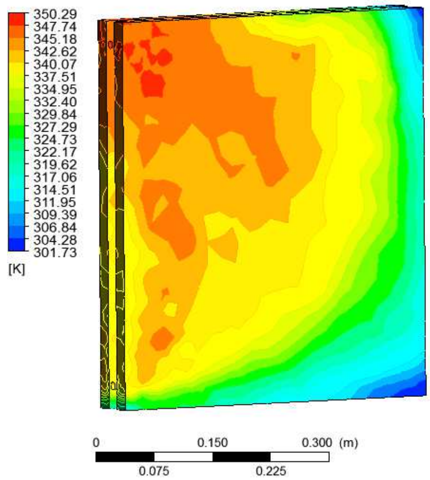

Figure 14 20% PCM slurry thermal field variation distribution after 3600 seconds

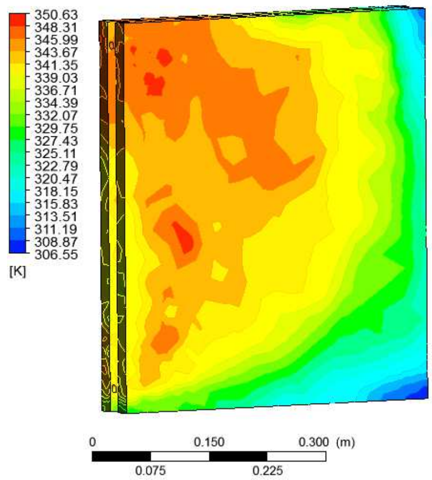

Figure 15 30% PCM slurry thermal field variation distribution after 3600 seconds

4 Conclusion

Laboratory tests of water slurries with PCM participation were conducted

with the intent to determine the variations of selected physical parameters such as viscosity, thermal diffusion and specific heat. The obtained parameter values that characterise PCM slurry properties were compared with the parameter values of water utilised as a standard heat-transfer medium in heating systems. The determined PCM slurry physical parameters constituted input data for a numerical model. A numerical model of a heat exchanger in the form of a steel double-wall plate heater was developed as the test subject of the analysed heating system with the use of CFD methods.

Based on the results of the conducted model tests, the following conclusions were formulated:

- the obtained model test results confirm the possibility to utilise PCM slurry as a heat-transfer medium,
- the developed numerical model results need to be applied to a real heating system utilising PCM slurry as a heat-transfer medium,
- according to the performed numerical analysis, a heat-transfer medium in the form of a slurry with a 30% PCM addition exhibits the best properties.

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INCREASING THE EFFICIENCY LINE OF SURFACE TREATMENT PROCESSES OF THERMO-CHEMICAL REACTIONS BY USING

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Keywords: surface treatment, simulation, flexibility, efficiency

Abstract: The paper is oriented to the field of engineering production. Specifically, it focuses on the field of surface finishing on parts made of different grades of steel. These are surface treatments, using thermo-chemical reactions. In particular, alkaline blackening, or else burning and phosphating of zinc, also called bonderization. The paper deals with increasing efficiency and production possibilities on the line, which provides just these two metal surface treatments. With the help of simulation, a digital model of this line was created, where possible improvements of its production possibilities were tested. The task was to increase the flexibility and elasticity of production and ensure the fulfilment of orders in the greatest possible satisfaction of customers and in the shortest possible time.

1 Introduction

It is often not enough to produce products manufactured in the machine industry according to the present drawing documentation by means of chip machining. In many cases there is also a requirement for the visual and surface treatment of these parts. This coating is often required, either for aesthetic reasons or to improve the surface properties of the parts. Alkaline blackening and phosphate of zinc coatings are also suitable for these conditions. These coatings are characterized by the following properties [1].

Alkaline blackening of steel materials is a proven process between steel surface treatments. It is a way of colouring steel products to ensure the appearance, abrasion resistance and corrosion resistance of the parts so treated in combination with adequate preservatives that support this treatment and extend its service life. Technically, a conversion iron oxide layer is achieved by means of hot alkaline blackening. The process consists in depositing thin oxide layers consisting of mixed oxides (FeO a Fe_3O_4) by immersion in a solution of acids, hydroxides or hot alkaline melt, for example a mixture of sodium hydroxide and sodium nitrite. This production process is also called noble rust. In contrast to conventional (Fe_2O_3), which peels from the parent metal, the oxides formed on the metal remain alkaline by blackening and prevent further oxidation. The treated surface is treated with a layer of preservative oil or varnish. This refined surface is achieved by a series of basic steps: Degreasing products, pickling, preheating and the blackening process itself. In the production process, it is necessary to maintain the necessary fluid temperatures, which range from 55 to about 142°C, depending on the operation.

Advantages of alkaline blackening (Figure 1):

- improves the appearance of components,
- increases abrasion resistance and improves corrosion resistance in combination with suitable impregnating oils,
- the dimensions of the parts to be treated remain unchanged, the coating being applied has a thickness of 0.5 to 2.5 µm,

- long-term durability of the treated surface with suitable treatment.

Practical application of alkaline blackening:
- manufacture of weapons,
- manufacture of measuring instruments,
- production of binoculars,
- Engineering industry,
- etc.

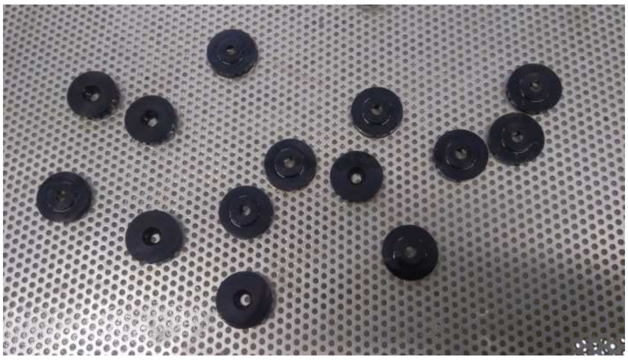

Figure 1 Components after alkaline blackening and conservation

Zinc phosphating is a chemical treatment of metal surfaces that creates corrosion-resistant coatings, minimizes surface friction and improves abrasion resistance (Figure 2). These coatings are electrically nonconductive, resulting in a reduction in the corrosion current. In this chemical process, an insoluble crystalline layer of phosphates and zinc is formed, which are neither soluble in water nor in organic solvents, thus having very good adhesion to the parent metal and thus providing a better adhesion of different kinds of paints. It is also possible to preserve the phosphate layer itself by means of a preservative oil, but this surface gives the possibility of good bonding of paints, waxes, lubricants, which reduces friction, varnish and the like.

Advantages of zinc phosphate layer:
- corrosion protection of metals,
- improvement of sliding properties,
- serves as an insulator,
- ability to bind another layer of adhesives,
- suitable for subsequent mechanical treatment (pressing, cutting, pulling, etc.),
- a protective layer of approx. 2 μm thickness.

Practical application of phosphating:
- surface protection layer of brake components,
- protection of the gear surface when running in gear systems,
- more durable alternative of primer for further dyeing process.

Figure 2 Brake disc with surface treatment phosphate of zinc

2 Original condition of surface treatment line and its properties

The production line on which both surface treatments are carried out consists of:
- 13 tubs of 180 l volume with chemical solutions and water rinses (Figure 3),
- gantry crane for material handling,
- an exhaust system to eliminate chemical vapours,
- material preparation workplaces,
- the final material inspection workplaces and packing workplaces.

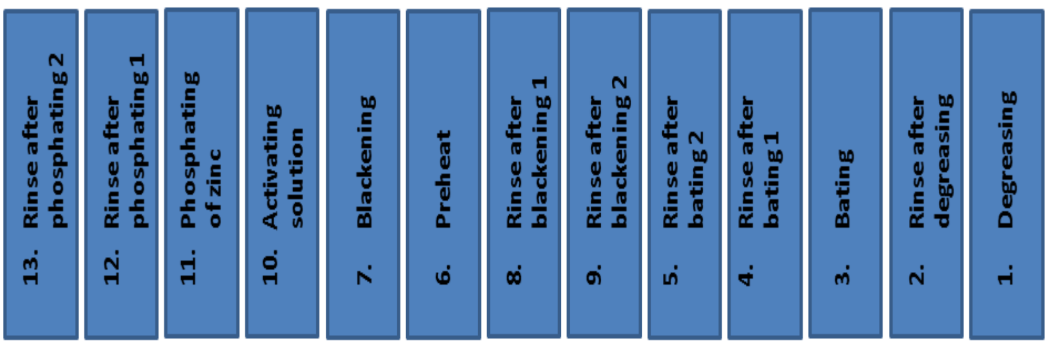

Figure 3 Schematic representation of tubs on the surface treatment line

Comparison of the surface treatments in question

The technological process and its sequence in the alkaline blackening process can be seen in Table 1. In the whole process it is necessary to observe the prescribed temperature and time ranges for individual operations [2].

A process similar to alkaline blackening is a phosphating of zinc process. The technological procedure of this surface treatment is shown in Table 2. It is also necessary to observe the prescribed temperatures, the sequence of operations and the time frame of individual operations in order to achieve the necessary surface quality.

Table 1 Technological process of alkaline blackening

Odred	Temperature	Time	Production description
		10 min.	Input and preparation of input material
Tubs no. 1	55-99^{0}C	1-6 min.	Degreasing of parts
Tubs no. 2	ambient temp	30 sec.	Rinse after degreasing
Tubs no. 3	15-30 ^{0}C	5-15 min.	Bating of the solution 15% HCl, removal of corrosion residues
Tubs no. 4	ambient temp	30 sec.	Rinse after bating no.1
Tubs no. 5	ambient temp	30 sec.	Rinse after bating no.2
Tubs no. 6	60-70 ^{0}C	3-5 min.	Preheat
Tubs no. 7	135-142 ^{0}C	12-20 min	Blackening, time and temperature depends on the material composition of the parts
Tubs no. 8	ambient temp	30 sec.	Rinse after blackening no. 1
Tubs no. 9	ambient temp	30 sec.	Rinse after blackening no. 2
			Drying and subsequent applying of parts with preservative oil, subsequent packaging of finished products

Both production processes of surface treatment are placed on one frame and form one common workplace for both technological processes. This is because the processes are very similar and, in many parts, identical. In this way, the space and personnel that both processes are saved (Figure 4) [3]. The disadvantage of the current line structure is its low flexibility. It is not possible to perform both processes without restrictions at the same time. Depending on the needs and orders for individual finishes, the production currently operates in alternating mode. This means that one process is always performed during one working day and not simultaneously. However, this solution means for the customer that it takes at least 2 business days to fulfil both the phosphating of zinc and alkaline blackening process. As there is currently a greater demand for alkaline blackening, it often happens that the line is doing this process for several consecutive days, and orders for the second phosphating of zinc process have to wait several working days. The production ratio is about 70:30, (alkaline blackening: phosphating of zinc). Therefore, the worker working on the line performs one technological process of one surface treatment during the whole production change. In this process, one more person is required to prepare the material before the process as well as to complete it after the process and also to package it for distribution [4].

Table 2 Technological process of phosphating for zinc

Order	Temoperature	Time	Production description
		10 min.	Input and preparation of input material
Tubs no. 1	55-99^{0}C	1-6 min.	Degreasing of parts
Tubs no. 2	ambient temp	30 sec.	Rinse after degreasing
Tubs no. 3	15-30 ^{0}C	5-15 min.	Bating of the solution 15% HCl, removal of corrosion residues
Tubs no. 4	ambient temp	30 sec.	Rinse after bating no.1
Tubs no. 5	ambient temp	30 sec.	Rinse after bating no.2
Tubs no. 10	15-30 ^{0}C	3-5 min.	Activating solution
Tubs no. 11	65-70 ^{0}C	3-5 min	Phosphating of zinc
Tubs no. 12	ambient temp	30 sec.	Rinse after phosphating no. 1
Tubs no. 13	ambient temp	30 sec.	Rinse after phosphating no. 2
			Drying and subsequent packaging of finished products

Figure 4 Production line of surface treatment

As can be seen in Tables 1 and 2, which show the technological processes, and from Figure 3, which shows the schematic arrangement of the line in both cases, the processes are very similar. The main difference is the final process, which has the largest share in the type and quality of surface treatment. From the technological processes it is well visible that the process of alkaline blackening requires more time. The main operation takes 20 minutes. In the phosphating of zinc process, the main operation takes 5 minutes. Figures 5 and 6 show simulations of the initial state of both production processes in one working day, or two working shifts, as the workplace operates in a two-shift operation.

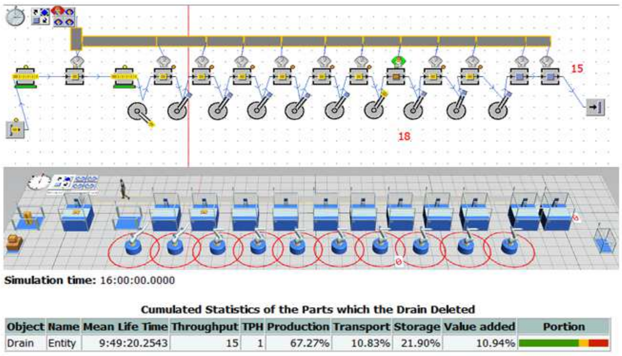

Figure 5 Simulation model of alkaline blackening in its original state

As can be seen in the simulation model in the alkaline blackening process, the line is able to process 15 batches in the current mode. One batch is considered to be a material that hangs on a special fixture to which parts of different shape and size can be hung. In the cumulative statistics generated by the program, we can see additional process data generated automatically by the Tecnomatix Plant Simulation software.

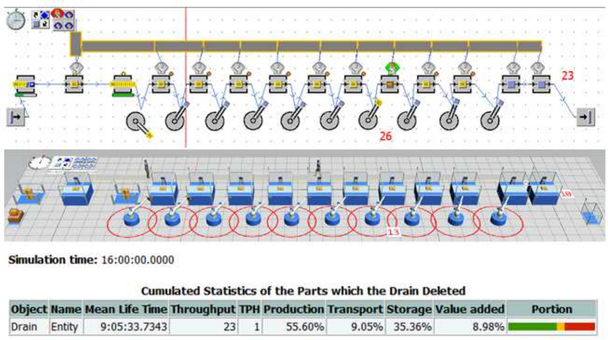

Figure 6 Simulation model phosphating of zinc in the original state

Also, from the simulation model phosphating of zinc (Figure 6) is evident, its less time consuming. During the working day the line is able to process 23 production batches. The company has determined as a unit of measure the weight of components it processes. The smallest production batch must be 30 kilograms and the line is capable of carrying 500 kg of material. However, weight does not play a role in software statistics; cumulative statistics are based only on the number of batches processed.

3 Linking both surface treatments into one concurrent production process and evaluating its properties

One customer often orders both types of surface treatment in one order and requests to process the order in the shortest possible time. As already mentioned, the line is not able to do two processes in one working day in the current production mode. This implies that processing of such an order takes at least 2 working days. However, it is optimal for the customer to wait for his order. Therefore, it is necessary to increase production flexibility. For this reason, the problem of how to increase production flexibility and ensure that both surface treatment processes can be done simultaneously within a single working day has been addressed. A simulation model was developed in the Tecnomatix Plant Simulation software module [5-7]. The design consists of an extension of the gantry crane and an additional track and hoist. Thus, it will be possible to perform two operations at the same time as the movement of the material along the line is conditioned by the movement of the hoist. The proposal will ensure that each surface treatment will have its own chain hoist and thus both alkaline blackening and phosphating of zinc can be performed simultaneously. However, it is necessary to employ second operator who will operate the new hoist, because one person would not be able to operate two hoists at the same time [8-15].

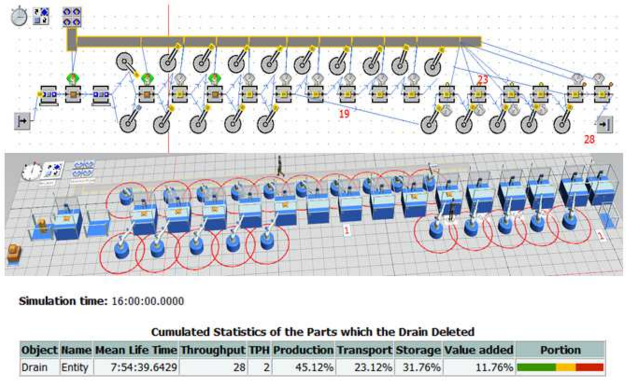

Figure 7 Simulation model for the proposal of surface treatment unification into a parallel process

The created simulation model of the design (Figure. 7) of the unification of production processes into a concurrent process shows that during two changes in one working day the line will simultaneously produce a total of 28 production hangers. The total added value of the parallel operation of the line is 11.76%.

4 Conclusions

Nowadays, when thinking about improving the efficiency or functionality of production lines and equipment, or making changes to entire production halls, companies do not have to make complicated and lengthy calculations about productivity and return on potential investment in technology improvement. The designs can be analysed in a relatively simple way with the help of simulation software, which, after setting several known parameters, will provide us with a lot of information on what production can look like after the change. It is possible to record various counters of individual devices, view graphical and statistical data and other necessary information that help management of the company to make the right decisions in the field of innovation and investment in interventions in production processes. In this way, time and money are currently saved in modernizing and improving production.

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3D SCANNING AS A MODERN TECHNOLOGY FOR CREATING 3D MODELS

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Keywords: 3D scanning, 3D scanner, Leica P30, digitization

Abstract: This paper is oriented to 3D scanning as one of the most important sectors of digitization of modern digital enterprises to create 3D digital models. The result of this technology are digital models that are characterized by being highly accurate compared to reality. Today, 3D scanner developers are constantly improving the scanning parameters of these scanners and working on optimizations to create scanners that are used not only in engineering or construction, but also in the medical process of creating 3D models of human body parts.

1 Introduction

In modern engineering, 3D scanning appears to be one of the most economical options for spatial measurement and subsequent 3D modeling. Compared to conventional laser rangefinders, 3D scanners differ in the number of points targeted per unit of time. The result of this measurement is the so-called "point cloud", which can be understood as a set of points, and the subsequent interconnection of the points by the triangles forms a triangulation network that describes in more detail the scan shape [1-8].

Figure 1 Leica P30 3D Laser Scanner Assembly

Digitization is a process where the properties of real objects are transformed into digital form.

The essence of measuring and at the same time creating 3D digital models using 3D scanners is actually evaluating the distance of individual points from the moment the beam is sent by the scanner. For a better idea, the overall model does not create a single scan, but creates a group of scans that depends on the severity and size of the scanned object. Scanning is followed by program modification of the scanned data, where the model is unified and filtered into the required parameters for further digitization procedures.

2 Detailed description of the Leica P30

The Leica P30 is a 3D versatile laser terrestrial scanner that is suitable for a wide range of standard scanning solutions (Figure 1). The biggest advantage of this scanner is its high performance and ability to work even in demanding conditions.

The scanning speed is 1 million points per second, up to 120 m. He creates images in HDR mode for highly detailed 3D cloud points. Another advantage of this scanner is its low noise when scanning data. With two vistas, the scanning range is 360 degrees in the horizontal direction and 270 degrees in the vertical direction. The internal battery life is 5.5 hours and the external battery life is up to 7.5 hours, which ultimately ensures the scanner

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lasts a full day of work. The scanning range of this scanner is around 700 Mpix.

Work with this scanner is also possible at temperatures ranging from -20 ° C to 50 ° C. This scanner is most often used for capturing plant model and production halls, scanning buildings, rooms, machines, as well as reconstructing architectural monuments or documenting the actual state if the drawings are outdated or outdated.

The software link between the user and the scanner is provided by the Cyclone software [2].

2.1 Scanner decomposition

The Leica ScanStation P30 (Figure 2) consists of:
- scanStation P30,
- ethernet cable,
- internal batteries,
- AC power adapter,
- power cable,
- power adapter for battery charging station,
- power station,
- three-point stand,
- tripod,
- scanner transport case.

Figure 2 Leica P30 3D Laser Scanner Assembly

2.2 Basic scanning process

In the first step, the scanner is removed from the carrying case and placed on an unfolded three-point stand. The stand itself should be placed in a horizontal position. The security screw connects the scanner to the stand. Three rectification screws and a built-in round vial are used to level the scanner horizontally (Figure 3).

At the location of the battery, the cover is removed by pressing the appropriate button and then the charged battery is inserted into the battery holder and reinserted. The scanner is turned on simply when the scanner is properly set up and fully turned on, the main menu appears on the graphical display (Figure 4).

Each scan must be stored in the project. If no user-defined project is created, the default is used.

Figure 3 Rectification screws with vial

Figure 4 Scanner main menu image

3 Reference target marking system

Use the softkey in the scan menu to mark the target position. Subsequently, by entering the target identifier, the target height can be set if necessary and the target type can also be selected from the list.

The center of the target is indicated by arrows and then returned to the project to create a list of targets from that scanner's scan position. The target type must be determined before determining the target position. Reference target information can be retrieved from the target list using the INFO function. It is also possible to see if all targets have been scanned correctly.

If the target is correct, "OK" will be displayed (Figure 5). If there is any missing information, the message "BAD" will be displayed. After the target check is performed, it returns to the results window and the targets are saved.

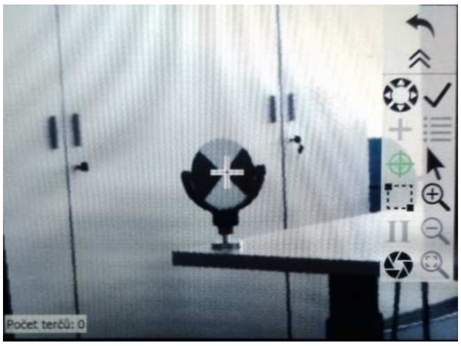

Figure 5 Targeting of references target

The target placement system is based on the target being visible. There must be no obstruction between the scanner and the target when viewed visually. Also, targets should not be placed in line with one another, as this could cause complications when joining scans. The target must be pointed at the straightest angle to the scanner. Furthermore, in order to link scans in Cyclone, at least two targets must be visible from the previous scan positions because of the non-registration of the target position when joining the scans. This procedure is repeated for each of the scan positions. In Figure 6, it is possible to follow the location of individual reference targets, which are indicated by yellow numbers. These targets are to a large extent logically placed on the corners of the hall for best visibility from multiple scan positions [9].

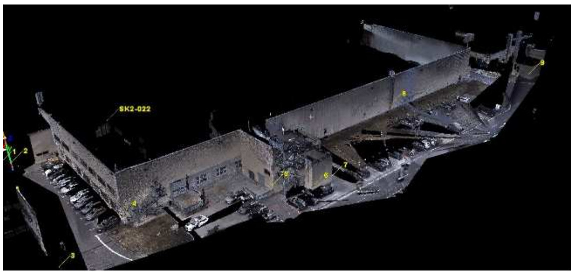

Figure 6 Scan of the side of the hall with a reference target number in CYCLONE

4 Data processing in Cyclone

Leica has developed a utility and processing program for the Leica ScanStation. The modular CycloneTM program (Figure 7) is the basis for the entire scanner work. It takes care of the entire workflow from selection and scanning, in connection with the interconnection of individual point clouds to the generation of the final model and subsequent visualization. The Cyclone software platform contains 6 modules. Each of these modules has its own specific purpose [9].

Figure 7 Registation of scan positions in CYCLONE [10]

5 Registration of "point cloud"

The point cloud registration is based on the exact placement of the individual clouds in the space according to a uniform coordinate system.

Registration joins:

- Same targets into one

  - Target 1 = 1 (SP1) = 1 (SP2) = 1 (SP3)
  - Target 2 = 2 (SP1) = 2 (SP2) = 2 (SP3)
  - Target 3 = 3 (SP1) = 3 (SP2) = 3 (SP3)

  (SP = Scanning Position)

- Determines the exact position of the scanner in each position based on the linked targets and places points in the space accordingly

- After registration, the scanner position from the first scan position becomes the zero (initial) point

6 Data processing procedure

Data processing procedure (Figure 8):

- the first step is to connect the scanner to the PC / USB via a USB cable and then copy the RAW data to the PC / USB,
- after opening Cyclon, it is necessary to create a new database for the imported project on the Cyclone server,
- click database in navigator to go to file / import scanstation data,
- registration of RAW data is created,
- the required scanning stations are inserted in the registration and targets are assigned,
- subsequently all entered data are registered,
- if all data is correct and registration is successful, the modelspace is then created,
- the modelspace created in this way is subsequently cleaned of data from noise and unwanted objects,
- to clean up data, the cloud is simplified with the Unify command,
- the last processing step is export to * .pts format.

7 Converting of scanned data

The conversion of the scanned data must be uploaded to Autodesk Recap™ because Autodesk programs do not accept file with suffix "pts." This suffix is the output of Cyclone after data registration. In Recap, this data is then converted with the extension "rcp.", Which is then suitable for the next modelling process that is done in Revit "rvt.".

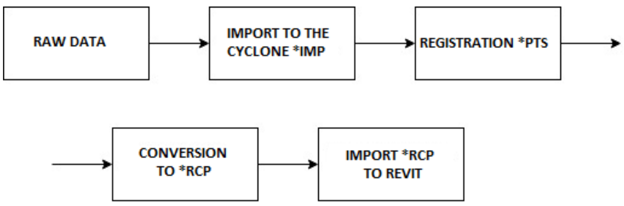

Figure 8 The entire process of data processing to the output suitable for Revit software for further processing

8 Conclusions

Currently, the reverse engineering industries will not do without 3D scanning technology. The main reasons, as mentioned, are its economic and technological aspects, which makes 3D scanning the best way to create 3D models.

In modern companies it is very important to orientate in this topic because of shortening the “time to market” by putting these 3D indoor scanners into practice. The main reason is not only the creation of 3D models of halls and factories but also layouts and also comparison of existing workplaces in order to optimize production and similar elements related to the overall production of products.

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HOW DIGITISATION IS DISRUPTING AND TRANSFORMING INDUSTRY

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Keywords: disrupting trends, transformation, digitisation, maintenance worker, industrial engineering
Abstract: The article deals with digitisation and digital technologies, which disrupt today´s classical processes in the Industry. Behind the scenes of the world's leading industrial and manufacturing factories, a deep digital transformation is underway. This is due to new digital technologies (disrupting technologies), which allow to shorten delivery times, increase resource utilization and maximise product quality. This makes the factory more competitive. Selected digital technologies, to help increase the competitiveness of factories, are described in our article.

1 Introduction

At present, all enterprises are looking for solutions in the area of increasing value-added, reducing costs in the context of changing market conditions in terms of financial, technical and personnel. Only copying approaches and methods in business change need not lead to the overall preservation of the competitiveness of the industrial production system. Businesses are beginning to realise that production processes are influenced by customer requirements, information technology, machinery and the environment in which the factories are located. For this reason, they need to reconfigure enterprise manufacturing and support processes and seek support in digitisation and exponential technologies. Historical developments, as well as the impact of globalisation and megatrends, have instigated the need for process change in individual industries. The changing customer demands put great emphasis on the flexibility of production, innovation, and flexibility to respond to changes. It is needed to quickly modify the manufacturing processes in the factories, which is often time-consuming and costly. Many countries and groups of states have prepared their own initiatives to improve the status of individual industries and industrial production. One of the best-known initiatives, especially in the Slovak republic is the Industry 4.0 concept from Germany. Other well-known approaches and initiatives are the Factories of the Future or the Smart Industry and others. The aims goal of these initiatives is to increase the competitiveness of each enterprise through digitization and create so called Smart factory, later Intelligent factory.

Smart Factory (Figure 1) is a type of factory that can handle fluctuations in demand over time, can produce most efficiently and is resistant to machine and equipment failures. In such a factory, people, machines and resources can communicate and work together. If a malfunction occurs, the machine reports itself to maintenance and also identifies the problem. A product in such a factory with the help of RFID chips can control its flow in production, knowing which individual parts it consists of and where it is heading. This implies that the product itself is actively involved in the production process. In such a factory, Smart Logistic, Smart Grid, Smart Buildings, Smart Distribution and "Smart Everything are integrated into one complex. In Smart Factory, the individual cells do not work in isolation, but everything is connected and works together effectively. A Smart Factory can integrate data from shopfloor or whole factory, human and operational assets to manage production, maintenance, inventory tracking, digitalisation, and so on. This can result in a more efficient and flexible system, reduced production downtimes, increased ability to anticipate and adapt to market changes, and thus better competitiveness.

Therefore, production factories need a realistic picture of their current state, the risks, and opportunities involved in digitising their processes, the implications of autonomous objects and implementation of initiatives such as Industry 4.0, in order not to jeopardize their market presence and effectively manage their processes [1,2].

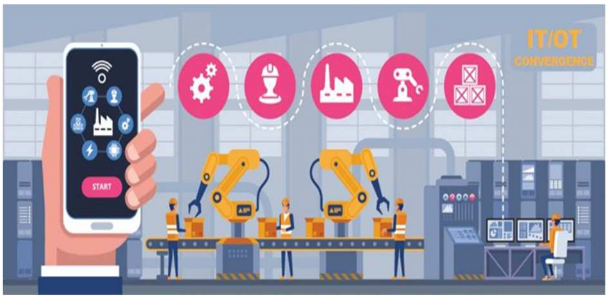

Figure 1 Digitisation in Smart Factory [3]

In modern industrial practice, innovative solutions for the improvement of processes or whole production or logistical systems are continually proposed. To be able to implement new technologies arising from the Industry 4.0 principles, companies must be able to combine the use of both, the latest and the available technologies. While using them, it is imperative for businesses to be aware of the current development trends. Thus, it is necessary to compile a list of technologies based on automatic exploratory (probing) principle that would automatically search for new classical and digital technologies. This list of technologies would serve the business as a basis for assessing the fitness of new technologies for the purpose of increasing the business' performance and its technological level. Given that society as a whole is influenced by technological advances, the industry will also face new challenges and needs. This will be mostly felt in the auxiliary and service processes, as they have technologically developed somewhat more slowly than the main production processes. Over the last 5 years, maintenance and technical service have begun to form a sophisticated system [4].

2 Digitisation and it's disrupting in the factories

Globalisation makes factories meet competitors in a completely different way than before. Manufacturing isn't about huge factories and long assembly lines anymore. Gone are the days of papers drawings, 2D schematics, spec sheets, and punch cards. Now, processes are digitised. Designs are completed in 3D CAD files; digital twins exist to mirror the objects they're building, and everything connected via the internet of things [5].

The term of digitisation resonates in the media, at conferences, in articles and in various forums, mostly only in general terms. Just in some only research and overview articles are good examples of implementation of digitisation and new trends in factories (Figure 2). We perceive digitisation meaning and its definition as something going on around us, but often without further concretization. But a close look at this often ruminate concept can really reveal its great potential for each enterprise.

Figure 2 Control of the production system with digital data [3]

In factories, digitisation also brings together the world of traditional information technology and the operating environment of manufacturing technology, which until recently was unthinkable and literally taboo. Here too, the benefits are evident. Immediate overview of productivity, the possibility of introducing a high level of automation of production processes, gradual robotization of an increasing number of production operations, implementation of selected functions of so-called artificial intelligence, coordination of production processes within distributed and globalised production, etc. A separate chapter is the emerging IoT (Internet of Things), Industrial Internet of Things (IIoT) solutions where their functional focus and applications for the business environment appear to be limited only by the technical and creative capabilities of developers and designers.

That's digitisation. So how does it transform the manufacturing industry [6,7]? In section 2.1 - 2.3 are four examples of the possibilities [7].

2.1 *Manufacturing will move a lot faster*

The first thing is that the digitisation transforms the manufacturing industry and to result is the speed of manufacturing of each factory. Driven by rapidly changing consumer tastes and an accelerated pace of new product introduction/innovation. The manufacturing process must search a reconfigurable way, for the best way to adapt. Increasing productivity is one of the results of implementing digitisation, allowing projects to move faster and manufacturers to hit more key deadlines. For example, manufacturers will be able to rapidly move from design to floor and back again as changes come through from the engineering team. In these days is this process exceptionally manual in many circumstances. 3D designs are converted into 2D spec books, and then those books are delivered to machinists on the floor who review and "redline" (literally mark-up) the books. Then those books are returned to engineering teams for revisions. In this process is a lot of inefficiencies:

- Printing a spec book might take hours with complicated designs.
- Redlining need to be done page by page, rather than simply reviewing the changes.
- Delivering is fine if the floor is below you. But what do you do when the factory is too far? For, example between Europe and Asia?

And the problem is that this process is entirely manual. Here does not exist so-called auto-check and of course, any opportunity for any innovation and process optimisation. Digitisation transforms these old processes and makes these processes more efficient by solving these problems. With this are opens the door for modern manufacturing innovation [8-18].

2.2 Digitisation is the best step towards the Industrial Internet of Things (IIoT)

The Industrial Internet of Things (IIoT) is a concept of a total product data loop. Nowadays every machines or equipment are loaded with sensors already in a manufacturing process due to, those sensors provide continuous feedback throughout the manufacturing supply chain (the reason is: maintenance of these devices, planning of the production process and so on). In response to real data from the processes like maintenance requirements and wear and tear, the manufacturing process can be improved. Some refinement happens automatically, for example, M2M communication, but some data is fed into business intelligence (BI) tools and dashboards. And these things giving people the ability to find efficiencies. The kernel of these critical processes is data. These data can be gathered and managed on a whole range. And that data can only be reasonably gathered and managed if it's an entirely digital product:

- Designs can be changed automatically in response to environmental challenges.
- Changes can be pushed automatically to the shop floor.
- Products can be altered as they roll off the line.

In the end, we may achieve a point where automation and artificial intelligent continuously optimise existing designs, layouts, and so on in response to information from real processes (results is the concept of the Digital Twin). In results will be that the engineers to focus on the innovation of new products.

2.3 Global manufacturing processes

The major problem of classical processes is that factory struggle if they're manufacturing across multiple locations, it means for example, in Europe and Asia. Nowadays is the manufacturing a global industry and in some cases is this a huge problem, but other times it is an advantage. Digitisation can offer to benefit for global manufacturing value chains for a few reasons. The first point is, that the data is easier to share. It's much easier to share files in the network than it is to send files through the mail. Even if the files are sent and then printed out, that's another data translation, and thus another vulnerability for each enterprise. The second point is, that the follow-the-sun manufacturing is more realistic. When factories moved offshore and engineering consultants started becoming more common (especially in the BRICS countries), for the first time follow-the-sun manufacturing started to be perceived as an attainable reality. Nowadays, it is a very comfortable thing for each big enterprise. The idea is that as one plant or design office closes for the day, the next one in the time zone over is just opening up. Work can be handed off seamlessly to a new team, and there's never any "downtime" overnight. However, this is only possible if:

- Each factory can share data essentially in real-time across multiple global locations.
- If all the necessary data can be accessed by anyone, at any time.

The second point is so difficult, due to is that we overlook how important it is to ask for consultation or help of us experienced co-worker. Especially at engineering handoff points, when clarification is so often needed. That's not possible in the global enterprise methodology, so it's imperative that all the information is conveyed the first time. Digitisation can help in every field, for example, with both simple clarities but also with process enforcement. An excellent example from practice is that we want to have every field in a form to be completed. This process is not perfect, but with digitisation, we have levers can pull to increase compliance.

2.4 Pros and cons of the digital transformation in the factories

Each new approach has its pros and cons. Digitisation and Industry 4.0 have tremendous benefits, but they also have some difficulties. Many arise from technical shortcomings (obsolescence of technology processes), lack of readiness for digitisation and robot automation, human prejudice, unwillingness to accept new things, and so on. Here are some pros and cons of digitisation:

Pros:

- Unifying and cleaning up information in the factories.
- Implementation of automated systems - elimination of human errors.
- Time-saving - remote access and remote correction.
- Higher process reconfigurability.
- Development time - decreasing
- Better competitiveness.
- Lower operating costs.
- New information, new knowledge - linking with many new specialists in the area.
- Increase of the attractiveness of a factory that uses new technologies - workers like to brag about what they work with (hidden advertising).
- Expansion of exponential technologies.
- Increase in OHSAS.
- Increase in productivity.

Cons:

- Higher costs for implementing new technologies.
- Fear of the unknown.
- Hacking attacks, power outages and the Internet, etc.
- Double data backup.

- Older generations of people may not handle new technologies.
- Misinformation and hoax.

3 How digitisation disrupting of the maintenance management

Recently we all have been hearing a lot about Industry 4.0, Smart Manufacturing, digitisation etc. The first thought which comes to one's mind is obviously how is it going to affect me. Will it help or disrupt? Before we go in details lets first understand the key challenges faced by maintenance in today's world. How these new technological advances can play a role in approaching these maintenance challenges. Maintenance is always being looked upon as a money guzzler (an item of property - house, car, machines, devices, gadgets etc; that constantly fails to result in paying more to fix.) so the obvious challenge is to making maintenance as a Profit centre to a Cost centre. Controlling cost and expenses is the biggest challenge faced by many maintenance managers. Managers are being pressured to do more with less. Another key challenge in this time of high-pressure situation is to keep the team motivated and in the right mindset to foster a culture of Innovation. Managing workload balance, stress-free atmosphere, providing equal opportunity and space to each individual for his own development are some of the few aspects that need to be taken care of.

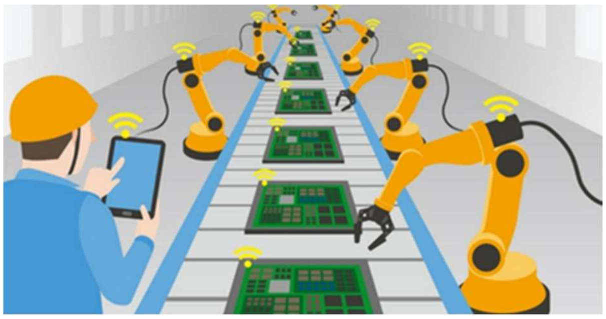

Figure 3 Maintenance worker in Smart factory [3]

So, let's explore how these new technological advances such as Smart / Intelligent machines (Figure 3), Predictive analytics, Artificial Intelligence and stuff like this will help the maintenance team in future. Normally whenever we initiate new initiatives the first question raised is how much CAPEX (capital expenditures - the money, a factory spends to buy, maintain, or improve its fixed assets, such as buildings, vehicles, machines, equipment, or land.) is required? What is the ROI etc. Implementing these new technologies need not be always costly/expensive. Simple intelligent sensors gather information, sending it to cloud where the machine learning and predictive analytics model plays its vital role in developing a health index for the motor. This health index is calculated, monitored on a real-time basis. Based on the health index we do not only get the alerts, but we also get the prescriptive recommendations. With this, we can predict the failure or stoppages much early where one can act and avoid failures to happen in future. Maintenance man-hours are avoided as there is no need to keep a daily track of parameters, conduct costly predictive maintenance and above all avoid maintenance spares inventory cost. We do not need to keep a spare motor or a bearing etc. as the predictability of failures is improved so that we can plan for spares in advance once we get any alert. This way digitisation helps in avoiding various cost related to maintenance.

With real-time monitoring and predictive analytics, the maintenance worker will get more free time which they can utilize for competency development and training. Generating innovation ideas and implementing the same. This shift from reactive maintenance to proactive maintenance shall reduce stress as the surprise breakdowns get eliminated. In a nutshell, Digitalisation is a boon not only maintenance but stakeholders throughout the value chain too. It is here to stay and is evolving with new technologies, the time has come to catch up with these latest technologies and grow along with it.

4 Intelligent maintenance in the Industry

Predictive maintenance now enables factories to take their first steps toward designing the maintenance processes of their factories much more efficiently. This is absolutely vital, since 70 percent of the total operating costs for machinery, factories and other capital goods are generated during the service phase. This means that, alongside reliability, reducing service costs is increasingly becoming a priority. However, it is worthwhile considering predictive maintenance in the broader context of a completely digitised service chain. Only by linking previously separate service processes, from intelligent sensors, proactive maintenance, innovative service technologies and logistics all the way to improved engineering, for example, is it possible to achieve the ultimate objective – factory that have the very highest levels of availability with costs as low as possible. Instead of isolated solutions, must be used specialized, systematically and reliably linking service processes (Figure 4), digitised from start to finish. Sectors such as the aviation industry have employed this condition-based maintenance approach for years. The aim is now to transfer this method to other industries and supplement them with new analysis opportunities. The advantages of this next generation maintenance solution can be seen in concrete maintenance and servicing savings.

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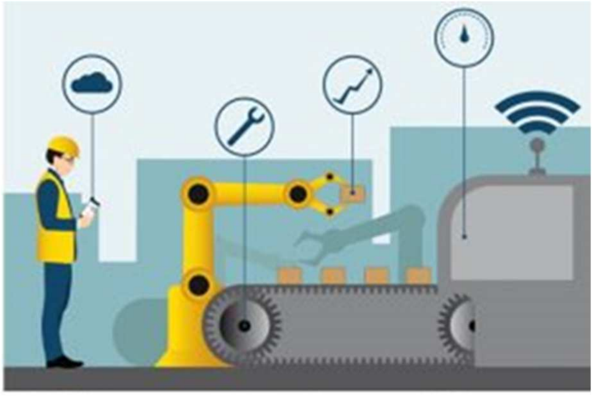

Figure 4 Maintenance worker in diagnostics process [3]

The next generation of the maintenance solution brings a digital transformation to the service phase. It completely covers the digitised end-to-end service approach and leaves no question unanswered when it comes to advising. Added to this is a comprehensive implementation package embracing design, transformation and operation. Factories can use this to design the service for their processes in such a way that they can be operated in the most reliable, cost-effective and sustainable way possible. It also draws on the established concept of TPM (Total Productive Maintenance), which focuses on the continuous improvement of production – with zero defects and outages as well as no loss of quality.

5 Operator 4.0 in the maintenance management

The vision of the Operator 4.0 is generally aimed at building relationships based on trust and interaction between people and machines, enabling smart-based businesses to leverage not only the power and capabilities of smart machines but also empower their operators with new skills and technical support to fully exploit production the possibilities resulting from the Industry 4.0 concept (Figure 5). These technologies, which are already in use by several factories today, include augmented reality, virtual reality, collaborative robotics, and so-called wearable sensors that sense human body functions [11].

In addition to strengthening physical skills, factory digitisation also requires a change in workers' knowledge and behaviour. Based on its Future of Jobs Report, the World Economic Forum has defined 10 skills that will characterise the Operator 4.0 in 2020 (Figure 6).

Figure 5 Maintenance worker in Smart factory [12]

Worker skills in 2015	Worker skills in 2020
1. comprehensive problem solving	1. comprehensive problem solving
2. teamwork	2. critical thinking
3. people management	3. creativity
4. critical thinking	4. people management
5. negotiation	5. teamwork
6. quality control	6. emotional intelligence
7. customer support	7. evaluation and decision making
8. evaluation and decision making	8. customer support
9. ability to listen actively	9. negotiation
10. creativity	10. cognitive flexibility

Figure 6 Worker skills of Operator 4.0

An ideally qualified maintenance technician should be able to cope in the near future with a "multipath" compound from the following disciplines:

- Technical expertise – mechatronics.
- Methods - the routine use of TPM principles.
- IT technologies - gather information and their analysis and transformation into information and knowledge.
- The spectrum of technical problems that a maintenance technician has to solve requires of the multidisciplinary expertise in the areas of electrical engineering, mechanics and control systems, with the degree of their detail, given by specific manufacturing technologies, and by their trouble-free operation is a responsible technician.

6 Conclusions

The article gave an insight, how digitisation disrupts the established things in the industry. This disruption will be caused, that workers will be used new technologies to strengthen their skills, increase safety and streamline work activities across all factory processes. As the industry continues to move towards digitisation, automation and robotics, many of the activities that are now manual today, will be changed or disappear.

Each enterprise should not underestimate the development chances brought by the emerging digitisation, especially factories. New trends, which are described in this article, were also starting to change some of today's factories. Over the past 30 years, corporate culture has evolved considerably. But with the coming of Industry 4.0 will change significantly. Without building the right digital culture, management is not able to maintain the necessary talents in factories. The way of thinking supporting the use of new technologies should be highly collaborative, going beyond the boundaries of the business towards partners and customers. Only in this way is it possible to achieve the key idea of the Industry 4.0 concept - integration. However, it is only possible to successfully develop these ideas in an environment where these initiatives are supported at the level of top management.

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