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THE CONCEPT OF RELIABILITY MEASURE OF RECUPERATOR IN SPRAY BOOTH

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Overspray sediments deposited on the recuperator fins gradually reduce the cross-section of the recuperator channels. The result of this process is the increase in airflow resistance and thermal resistance during heat transfer. Both phenomena have a negative impact on the reliability of the device. This paper presents the concept of recuperator reliability measures. For this purpose, the essential requirement of reliability (indestructibility) was formulated and damage was defined by identifying it with the loss of air flow reserve and reserve of heat transfer efficiency. On this basis ability features of the heat recovery unit were assessed. Limits of features and critical time of recuperator loss of ability were also assessed.

Keywords: *reliability, spray booth, recuperator, overspray sediments.*

Odkładające się na lamelach rekuperatora osady lakiernicze powodują stopniowe zmniejszanie przekroju poprzecznego kanałów rekuperatora. Skutkiem tego procesu są wzrosty oporów przepływu powietrza oraz oporu termicznego przy wymianie ciepła. Oba zjawiska wpływają negatywnie na niezawodność urządzenia. W artykule przedstawiono koncepcję miary niezawodności rekuperatora. W tym celu sformułowano podstawowe wymaganie niezawodnościowe (nieuszkadzalność) oraz zdefiniowano uszkodzenia utożsamiając je z utratą zapasu strumienia powietrza oraz zapasu efektywności wymiany ciepła. Na tym tle określono cechy zdatności urządzenia, granice ich obszarów oraz krytyczny czas utraty zdatności rekuperatora.

Słowa kluczowe: *niezawodność, kabina lakiernicza, rekuperator, osady lakiernicze.*

1. Introduction

The recuperator is a technical device used in ventilation systems, also in spray booths. Due to the technological requirements related to coating technology, it is important that this process is carried out in appropriate conditions, determined primarily by the right temperature and air purity [30]. The purpose of the use of a recuperator is to recover the waste heat from the exhaust air from the working chamber spray booth and preheat the fresh air taken in from the outside. Inside the recuperator there are alternately hot and cold air ducts separated from each other by thin aluminum fins. In the cross-flow recuperator, streams of warm and cold air flow perpendicularly to each other. Heat is exchanged between the air streams via fins. Figure 1 shows a spray booth with a cross recuperator and a diagram of air circulation during the booth operation in the painting mode. Fresh air taken from the outside is pre-heated in the recuperator (1) then, after having been cleaned in the prefilter (2) it is heated to the required temperature by a burner with a heat exchanger (3). The heated air is finally cleaned in the supply filter (4) and blown into the working chamber (5). Coating takes place in the working chamber and during this process the overspray is formed. Volatile organic compounds (VOC) and varnish particles, that are not located on the varnished surface, float in the overspray. The air passing through the working chamber takes the overspray with it and leaves the booth through the paint stop filter (6) which retains the paint particles. Then the purified air through the exhaust duct, goes to the recuperator (1) where it partially transfers the heat to the drawn-in fresh air.

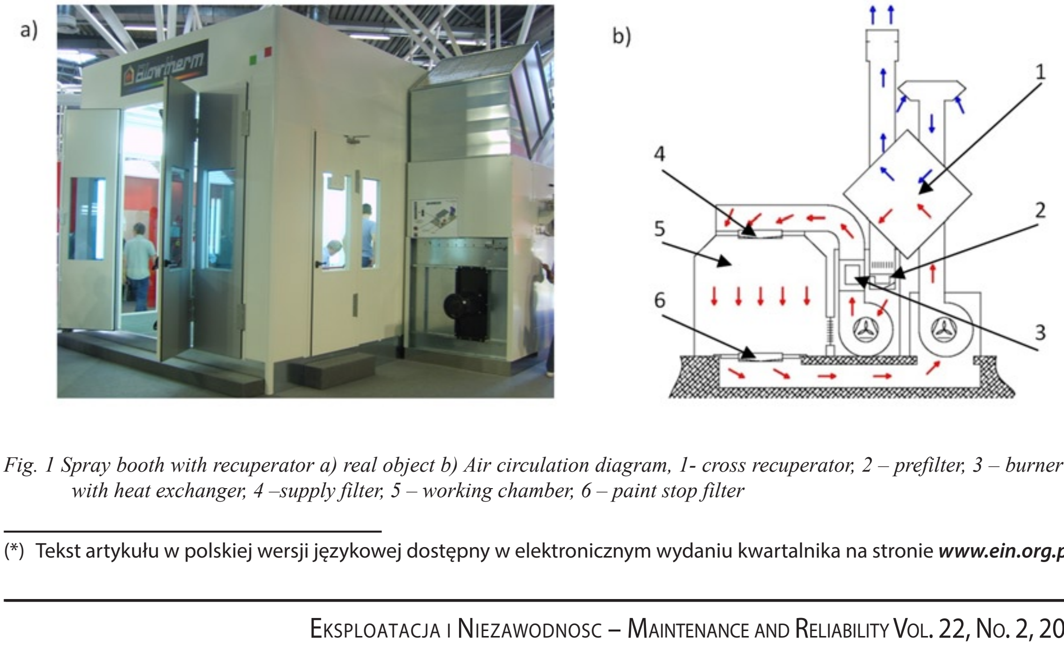

Fig. 1 Spray booth with recuperator a) real object b) Air circulation diagram, 1- cross recuperator, 2 – prefilter, 3 – burner with heat exchanger, 4 –supply filter, 5 – working chamber, 6 – paint stop filter

Operation of the recuperator in the spray booth is accompanied by the process of sedimentation of overspray particles on the recuperator fins inside warm air ducts. Research and modeling of heat exchanger pollution are carried out [6]. A model of overspray sediment formation inside a cross recuperator is presented in [14]. A direct consequence of this phenomenon is the reduction of the cross section of the hot air ducts in the heat exchanger. This has been described in more details in [12]. As a result, it leads to an increase of airflow resistance

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** and thermal resistance in the heat exchange process. The latter causes a decrease in the efficiency of heat recovery in the recuperator, while a decrease in the volume of exchanged air leads to the risk of explosion. The process of sedimentation of overspray particles on recuperator fins is destructive, having a significant impact on the reliability of recuperator operation.

Safety requirements for paint and varnish application have been raised in publication [18], defined and updated in relevant European Union regulations [29] and other global legal acts, among others in Australia [32], in the United States [34] and in New Zealand [33]. The requirements of local regulations have been presented in the Guideline for Spray Finishing Particulate Recommended Practice developed by the National Air Filtration Association [30]. A similar study was published in the United Kingdom [31]. The impact of regulations on the car coating industry is presented in the study [35]. Two main hazards have been identified in the spray booths: intoxication of the painter and formation of an explosive mixture. The method of determining risk explosion for spray booths used for powder coating is described in [25].

Reducing the growth rate of paint deposits is possible, among others, by improving the efficiency of cleaning the air removed from the spray. The efficiency of paint stop filters depends on their type [4] and the size of the paint particles carried in the overspray. The analysis of the efficiency of air purification from varnish particles as a function of their size is presented in [1]. Comparative results of filter efficiency are presented in [4], while a broader scope of research work is included in the summary of the completed research project [3]. The size of the particles depends on the kind of varnish and application parameters. The analysis of varnish particle size is presented in publication [20], while significantly expanded results are contained in [21]. A separate analysis of the formation of paint mist and air purification for technology without compressed air (airless spray painting) is presented in [23].

The issue of purifying the air removed from the paint shop is still valid; a state of the art review of the matter is presented in [22]. Works are carried out on new technologies of air filtration in spray booths [7]. Wet gravity cleaning techniques [10] and medialess dynamic filtration [26] methods are considered. So far, no air purification technology that ensures complete removal of overspray particles has been developed. Biofiltration technologies are being considered for the removal of volatile organic compounds [8]; and among others the use of biological stream filtration [24] or fungal biofilters [16] has been proposed.

Deterioration in the level of the device reliability is the consequence of sedimentation of varnish particles on the recuperator fins. As of today, the technical documentation of spray booths equipped with cross recuperators does not contain guidelines for periodic inspections of the recuperator condition and the frequency of its cleaning. Identifying the main features of the recuperator's ability and assessment of their limits will help determine the frequency of inspections and cleaning of the recuperator to ensure the safety of coating process. This paper proposes measures of the recuperator reliability and estimation of the critical ability time of the recuperator t_{kr}, after which it gets damaged, assuming that its important reliability requirement is indestructibility.

The critical time of the recuperator ability t_{kr} is also an indicator for the frequency of inspections and maintenance works.

2. Reliability features

The following discussion assumes that the recuperator reliability is significantly affected by the process of overspray sediment deposition. It is a basic assumption which simplifies reality, neglecting other, less important processes that may lead to other forms of damage (e.g. mechanical damage). The presented influence of overspray sediments on the recuperator working parameters allows the assumption of two features determining its ability. For further analysis heat exchange efficiency reserve and air flow reserve are used. Loss of reserve in relation to each of these features is identified with the occurrence of damage and the transition of the device to a state of unreliability.

Bearing in mind the nature of the phenomenon leading to recuperator damage, in order to determine its measure of reliability, two features of ability were assumed: *heat exchange efficiency reserve* and *pressure drop reserve*.

2.1. Heat exchange efficiency reserve

This feature refers to damage identified with the state of the recuperator, in which the limit value k_{gr} of the thermal conductivity coefficient is reached. It refers to economic aspects related to waste heat recovery.

The efficiency of heat exchange in the recuperator is related to the heat flux $\dot{Q}(t)$ [1], which is dependent on the coefficient of thermal conductivity $\boldsymbol{k(t)}$ and the temperature difference ΔT between the air streams on both sides of the recuperator lamellas (assuming that this difference is determined and unchangeable in time):

$$\dot{Q}(t) = k(t)\Delta T \tag{1}$$

Heat exchange efficiency reserve $\boldsymbol{h_1(t)}$ is defined as:

$$h_1(t) = \dot{Q}(t) - \dot{Q}_{gr} \tag{2}$$

where $\dot{Q}_{gr}$ means the value of heat exchange efficiency reserve.

Noting equation (1), the relationship describing the heat exchange efficiency reserve $\boldsymbol{h1}\ (t)$ takes the form:

$$h_1(t) = (k(t) - k_{gr})\Delta T \tag{3}$$

The value of the thermal conductivity coefficient $\boldsymbol{k(t)}$ is determined for the recuperator, taking into account the impact of overspray sediments growing on the lamellas. Thermal conductivity $\boldsymbol{k(t)}$ is a random variable, because the growth of sediment layers on the lamella surfaces is a random phenomenon. For any point of time τ and the lamella's surface point described by coordinates (x_o, y_o). The $\{\boldsymbol{k(x,y,t)}\}$ process realization is described by the following relationship [17]:

$$k(x_o, y_o, \tau) = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_R}{\lambda_{TR}} + \frac{\delta_S(x_o, y_o, \tau)}{\lambda_{TS}} + \frac{1}{\alpha_2}} \tag{4}$$

where:

- α_1, α_2 – convective heat transfer coefficient [W/(m^{2}K)]; it is assumed that the value is determined,
- δ_R – thickness of fin [m]; it is assumed that the value is determined,
- $\delta_S(x_o,y_o,\tau)$ – thickness of sediment at the point of the lamella surface determined by coordinates (x_o, y_o) [m]; stochastic process $\{\boldsymbol{\delta_S(x,y,t)}\}$ realization in point of time τ,
- λ_{TR} – fin thermal conductivity [W/(mK)]; it is assumed that the value is determined,

1 In this work, the symbols of random variables are written in **bold**.

λ_{TS} – overspray sediment thermal conductivity [W/(mK)]; it is assumed that the value is determined.

To determine the feature of ability $\boldsymbol{h_1(t)}$ in point of time τ, the realization of the coefficient $\boldsymbol{k(t)}$ is determined by the formula:

$$k(\tau) = \frac{1}{xy}\int_0^y\int_0^x k(x,y,\tau)\,dydx \tag{5}$$

2.2. Pressure drop reserve

This feature refers to the damage identified with the state in which the limit value of pressure drop ΔP_{gr} in the recuperator channels is reached. The air flowing through the ventilation duct overcomes the frictional resistance appearing on the walls of the ventilation duct. This resistance, together with the diminishing cross-section of the duct, causes the pressure drop over its entire length, leading to a decrease in the volumetric air flow. Reduction of the volume of exchanged air results in the danger of creating an explosive mixture in the working chamber. It also leads to the risk of poisoning of the painter working inside [32].

Pressure drop reserve $\boldsymbol{h_2}(t)$ is determined by formula:

$$h_2(t) = \Delta P_{gr} - \Delta P(t) \tag{6}$$

where:

$\Delta \boldsymbol{P}(t)$ – pressure drop.

The pressure drop in the ventilation duct is a stochastic process $\{\Delta \boldsymbol{P}(t)\}$, whose realizations depend on the length of the channel and randomly time-varying unit resistance $\boldsymbol{r}(t)$:

$$\Delta P(t) = r(t)l \tag{7}$$

The resistance coefficient $\boldsymbol{r}(t)$ also known as unit pressure drop [17] depends on many parameters, including two that change their values over time:

$$r(t) = \frac{\lambda_F(t)\varsigma w^2}{2d(t)} \tag{8}$$

where:

$\boldsymbol{\lambda_F}(t)$ – dimensionless friction resistance coefficient; random value,

ς – air density [kg/m3]; it is assumed that the value is determined,

w – average air flow rate [m/s]; it is assumed that the value is determined

$\boldsymbol{d}(t)$ – hydraulic diameter of channel [m]; random value.

The hydraulic diameter for the channel cross-section in general form is determined using the equation [17]:

$$d = \frac{2ab}{a+b} \tag{9}$$

where a and b denote the dimensions of the rectangular cross-section of the channel.

Taking into account the time-varying randomly thickness of the overspray sediments $\boldsymbol{\delta_S}(t)$, the formula describing the realization of the equivalent diameter $\boldsymbol{d}(t)$ at the point of time τ takes the form:

$$d(\tau) = \frac{2ab - 4(a+b)\delta_S(\tau) + 8\delta_S^2(\tau)}{a+b-4\delta_S(\tau)} \tag{10}$$

The dimensionless friction resistance coefficient $\boldsymbol{\lambda_F}(t)$ changes its value over time due to the dependence on Reynolds number. For turbulent flow, the friction coefficient is described as follows:

$$\lambda_F(t) = \frac{0{,}3164}{\sqrt[4]{\mathrm{Re}(t)}} \tag{11}$$

The Reynolds number $\boldsymbol{Re}(t)$ depends on the hydraulic diameter equivalent to the cross section in the ventilation duct $\boldsymbol{d}(t)$. At the point of time τ it is determined basing on the formula:

$$\mathrm{Re}(\tau) = \frac{wd(\tau)}{\upsilon} \tag{12}$$

where υ is the kinematic coefficient of viscosity [m^2/s].

3. Limits of ability features

The above defined features create a basis for demarcation of the following areas of ability

– for *heat exchange efficiency reserve*:

when the recuperator is able (no damage)

$$h_1\left(\dot{Q}(t), \dot{Q}_{gr}\right) > 0 \tag{13}$$

when the recuperator is disable

$$h_1\left(\dot{Q}(t), \dot{Q}_{gr}\right) \le 0 \tag{14}$$

– for *pressure drop reserve*:

when the recuperator is able (no damage)

$$h_2\left(\Delta P(t), \Delta P_{gr}\right) > 0 \tag{15}$$

when the recuperator is disable

$$h_2\left(\Delta P(t), \Delta P_{gr}\right) \le 0 \tag{16}$$

4. Measure of reliability

It is assumed that the basic reliability requirement of the recuperator construction is its functioning without damage within a specified period of time. This approach is justified by the function that this device performs. Achieving the critical states described above identified in this work with damage, is tantamount to unacceptable deterioration of the functionality of the device. This significantly affects the safety and operational cost of the spray booth and the quality of the paint application process.

Given the above, it is assumed that the measure of reliability that characterizes the reliability requirement formulated above, is the probability of its fulfillment in the analyzed time period:

$$R(t) = P\left(\left(h_1(t) > 0\right) \cap \left(h_2(t) > 0\right)\right) \tag{17}$$

Therefore, the probability of recuperator operation with both analyzed ability features is determined. It should be noted that the relationship (17) determines the probability of two dependent events. This relation results from the dependence of both features on the process of particle sedimentation, represented here by the stochastic process $\{\boldsymbol{\delta_S(t)}\}$.

5. An analysis of ability features

It is assumed that the presented ability features depend on the constant construction parameters of the recuperator and the time varying thickness of overspray sediments $\boldsymbol{\delta_S(t)}$.

A preliminary analysis of ability features was carried out on the example of a recuperator dedicated to spray booths. The unit is a part of the offer documentation supplied by one of the entrepreneurs operating on the refinishing market [28]. This recuperator itself also was an object of study presented in [13].

For the presented recovery unit, the impact of sediments thickness on changes in formulated ability features was analyzed. Figure 2 shows the changes in thermal conductivity coefficient $\boldsymbol{k(\delta_s)}$ according to equation (4) and the corresponding changes in heat flux $\dot{Q}(\delta_S)$ according to formula (1). They affect the value of the ability feature $\boldsymbol{h_1(t)}$. The value of thermal conductivity coefficient $\lambda_{TS} = 0.082\pm0.003$ [W/(mK)] was taken for calculations. Measurement methodology and value results with error analysis for thermal conductivity of sediments are described in [15]. For calculations according to equation (4) the following values were used: thermal conductivity of aluminum $\lambda_{TR} = 200$ [W/(mK)], equal convective heat transfer coefficient for air on both sides of the fin $\alpha_1 = \alpha_2 = 50$ [W/(m^{2}K)], fallowing the documentation [28] the thickness of the recuperator fins was determined as $\delta_R = 2e{-}4$ [m]. Values of heat flux $\dot{Q}(\delta_S)$ were calculated for temperature difference $\Delta T = 40$ [K].

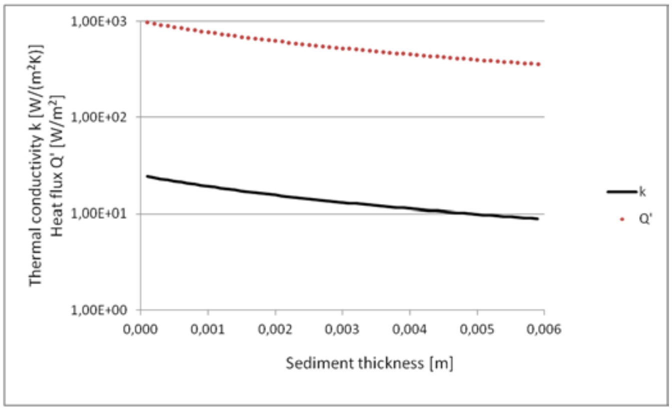

Fig. 2. Calculated changes in thermal conductivity coefficient $k(\delta_s)$ and heat flux $\dot{Q}(\delta_S)$

Figure 3 shows the increase in pressure drop as a function of sediment thickness $\Delta P(\delta_s)$. The pressure drop is associated with the ability feature $\boldsymbol{h_2(t)}$. Calculations were made according to equation (7). The following variable values were used: air density $\varsigma = 1.2$ [kg/m^3], average air flow rate $w = 5.56$ [m/s], kinematic coefficient of viscosity $\upsilon = 1.5e{-}5$ [m^2/s]. Fallowing the documentation [28] the following parameters of recuperator channels were determined: dimensions of the rectangular cross-section of the channel $a = 1.2e{-}2$ [m], $b = 1$ [m] channel length $l = 1$ [m], number of channels in the recuperator separately for hot and cold air $n = 60$. Overspray sediments grow up only in the ducts with warm air removed from the spray booth. Calculations of the pressure drop $\Delta P(\delta_s)$ were carried out for a single warm air channel, assuming that there is a uniform distribution of air velocity in all cross-sections of the channels and turbulent flow occurs. For the hydraulic diameter $\boldsymbol{d(t)}$ described by equation (10), a homogeneous, average value of sediments thickness $\boldsymbol{\delta_S(t)}$ was assumed.

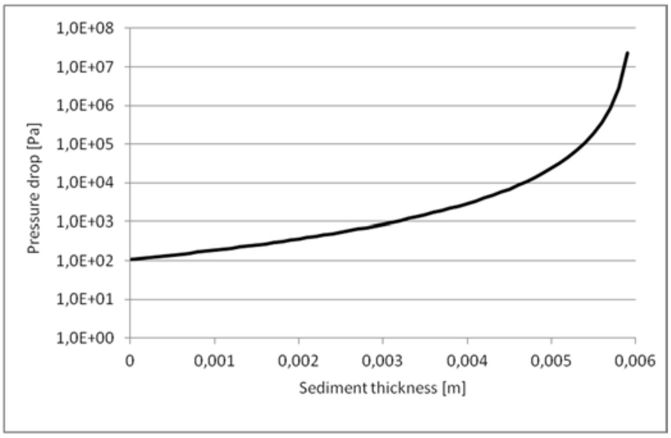

Fig. 3. Calculated pressure drop $\Delta P(\delta_s)$

Figure 4 shows the percentage changes of heat transfer efficiency and the inverse of pressure drop as a function of sediment thickness. The graph shows the inverse of the pressure drop of $1/\Delta P(\delta_s)$ to improve transparency in comparison with the percentage changes of the heat flux $\dot{Q}(\delta_S)$. The starting points of 100% for both parameters indicate their values for the clean condition of fins, not covered with sediments. The analysis of the presented graph indicates a much greater impact of the sediment growth process on the change of pressure drop, and as a result on the change in the value of the feature $\boldsymbol{h_2(t)}$.

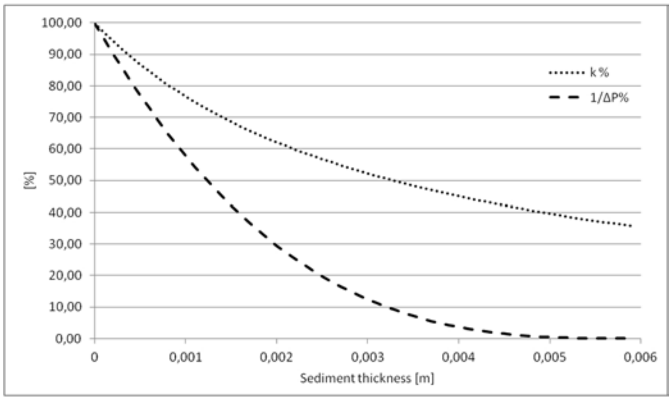

Fig. 4. Percentage changes in heat flux $\dot{Q}(\delta_S)$ and inverse pressure drop $1/\Delta P(\delta_s)$ depending on the thickness of the sediments

The growth rate of overspray sediments depends on many parameters and it is a process with variable dynamics. Figure 5 presents the results of measurements of sediments in three paint booths. The points presented in the graph represent average values from measurements after a given period of booth operation time. The trend lines show the average growth rates of sediments in each of the spray booth. The research methodology and their conditions were described in [13]. Measurements were carried out in spray booths not equipped with recuperators. Measurement points for technical reasons were located in each cabin on the air damper cover in the exhaust channel. This is the place where it is customary to install a recuperator (Figure 1). The measurement results were a basis for development of a simulation model of sediment deposition on the recuperator fins. The numerical model and simulation results are presented in [14]. The model assumes that the air velocity is the same in all cross-sections of the recuperator channels and that the flow is turbulent.

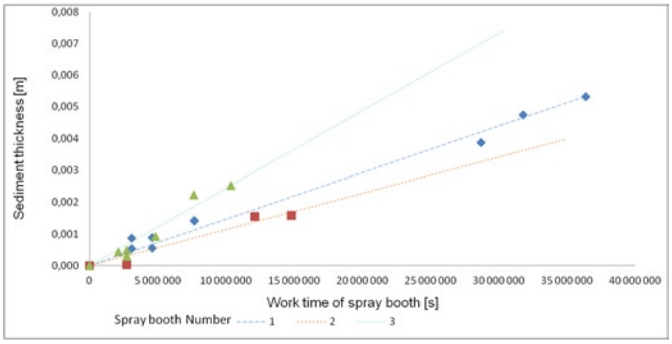

Fig. 5. Growth rate of paint deposits in three paint booths [13]

An analysis of the results presented in Figure 5 indicates a strongly random nature of the sediment build-up process. For example, trend lines of sediment thickness measurement results in booths No. 2 and 3 indicate more than twice the growth rate in booth No. 3 than in No. 2. This is primarily due to the random impact on this process of factors such as: total of summary working times in the painting and drying modes in the total operation time of the spray booth, setting parameters and transfer efficiency of the spray gun, efficiency of the paint stop filter, skills of the painter, shape and sizes of painted objects.

Based on the trend lines presented in Figure 5, the percentage changes in pressure drop and thermal conductivity coefficients in the time domain were developed for individual booths. The results are shown in Figure 6. On diagrams for booths 1, 2 and 3 are respectively marked pressure drops as *ΔP1*, *ΔP2* and *ΔP3* and the heat flux as *Q'1*, *Q'2* and *Q'3*. The calculations were carried out using the equations presented in section 2.

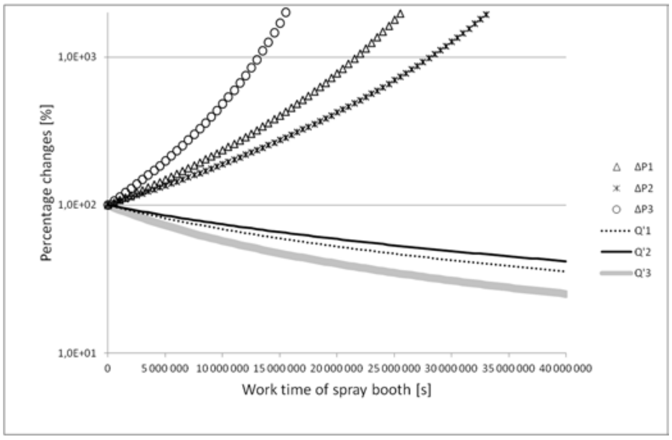

Fig. 6. Percentage changes in pressure drop (ΔP1, ΔP2, ΔP3) and heat flux (Q'1, Q'2, Q'3) in individual spray booths

Due to the exponential increase in pressure drop shown in Figure 3, the diagram in Figure 6 shows the fragments of curves that do not exceed the 2000 [%] value of changes. These values are the results of theoretical calculations that will not be achievable in a normal operation of the spray booth with a recuperator.

Comparing the dynamics of the percentage changes in the thermal conductivity coefficient and the pressure drop, a significant increase in the percentage change in the pressure drop relative to the percentage change in the thermal conductivity coefficient is noticeable.

The study of the paint booth operation process described in the work [13], observations and interviews with paint booth users provide the basis for estimating the values that are proposed in the ability features analyzed here as limits.

In relation to the ability feature $\boldsymbol{h_1(t)}$ identified with a feature of heat exchange efficiency reserve it is proposed to initially take the following as a limit value

$$\dot{Q}_{gr} = 0.5\dot{Q}_N = 500[W/m^2] \tag{18}$$

wherein Q is the nominal value of the heat flux for the new non-sedimented recuperator. The nominal value of the heat flux can be read from Figure 2 $\dot{Q}_N$ = 1000 [W/m^2]. At this value of the heat flux, the energy efficiency of the recuperator reaches half its nominal value, which reduces by half the estimated economic benefits of the spray booth user. It was considered that half of the savings obtained due to recovered heat constituted the profitability limit of investment costs related to the purchase and installation of a recuperator.

Regarding the $\boldsymbol{h_2(t)}$ characteristic, twice the nominal pressure drop is proposed as the limit value for the pressure ΔP_N

$$\Delta P_{gr} = 2\Delta P_N = 216[Pa] \tag{19}$$

As a nominal value of ΔP_N, a pressure drop on the recuperator in a clean state, when the recuperator fins are not covered with overspray sediments, was assumed. Figure 3 shows the changes in pressure drop calculated according to equation (7) depending on the thickness of the sediments. The initial value of the pressure drop for the sediments thickness δ_s = 0 [mm] is equal ΔP_N = 108 [Pa]. The total pressure drop in the ventilation ducts of the spray booth is individual for each booth. It is associated with many parameters and, above all, the length and cross-sections of the ducts, the number and type of fittings in ventilation systems, the construction of the heat exchanger for air heating, the types and cleanliness of air filters as well as the recuperator. On this basis, it was accepted that twice the nominal pressure drop on the recuperator is its critical value.

For the critical values proposed above and on the basis of faster changes in pressure drop as a function of sediment thickness, the $\boldsymbol{h_2(t)}$ feature was indicated as the leading feature in estimating the time of the loss of ability.

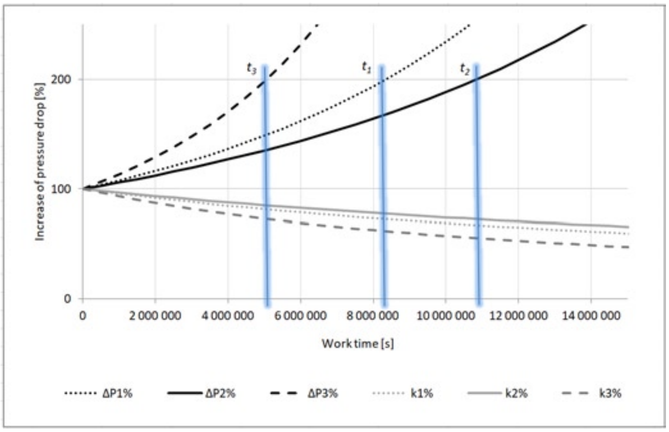

Fig. 7. Estimated doubling times of pressure drop

Figure 7 shows the estimated times at which the ΔP_{gr} limits were reached for individual booths. The times when the pressure drop doubled for each booth were marked successively as t_1, t_2 and t_3 adequately to the booth number. The doubling times for individual booths are respectively:

$$t_1 = 8346234 \text{ [s]}$$

$$t_2 = 10837105 \text{ [s]}$$

$$t_3 = 5061598 \text{ [s]}$$

These values are varied and it is particularly noticeable that the time t_2 is almost twice as large as the time t_3. The diversity of values is due to the strong randomness of the sediment grow up process.

Based on the above calculations, the t_3 value was adopted as the critical time of the recuperator's loss of ability, this is the shortest period in which damage will not occur

$$t_{kr} = t_3 = 5061598[s]$$

6. Summary

In the proposed model of the recuperator reliability in the spray booth, two ability features have been indicated: ***$h_1(t)$*** *heat transfer efficiency reserve* and ***$h_2(t)$*** *pressure drop reserve*. The features ***$h_1(t)$*** and ***$h_2(t)$*** have different variations depending on the thickness of the sediments. As indicated by the analysis the overspray sedimentation has a random character. The ***$h_1(t)$*** feature is associated with a decrease in heat recovery efficiency in the recuperator. It is economic in nature. However, the ***$h_2(t)$*** feature is associated with an increase in airflow resistance through the recuperator. Reducing the volume of air exchange in the spray booth can lead to increased concentration of overspray and VOC. This can result in poisoning of the painter or formation of an explosive mixture. This study indicates a much faster pace of changes in the ***$h_2(t)$*** feature as compared to the ***$h_1(t)$*** in the longer period of operation. Finally, the ***$h_2(t)$*** feature was recognized as dominant, which has a significant impact on determining the periodicity of inspection and cleaning of the recuperator.

The working time of the recuperator in undamaged condition was estimated at t_{kr} = 5061598 seconds, which is equivalent to 1406 hours of spray booth operation. After this time, it is required to carry out an inspection and clean the recuperator of overspray sediments. The results obtained relate to three spray booths and constitute preliminary values. Due to the heterogeneous growth rate of overspray sediments, it is difficult to estimate the exact times to reach the limit values by the ability characteristics. Acquiring and organizing the results of measurements of the growth rate of sediments in many spray booths will facilitate the determination of average and critical intervals of the paint booth operation time in which recuperator damage should be expected.

The proposed ability features illustrate the assumption that the reliability of the recuperator is significantly affected by the thickness of the overspray sediments without any other possible damage. A similar approach was presented in [19]. The condition of recuperator damage results in the loss of ability of the entire spray booth. The indicated features of the recuperator ability become also the features of the spray booths, but they are not the only features indicating the level booth's ability. By averaging the growth rate of sediments, an individual model of a spray booth as a multi-element system described in [27] can be created. The work [11] also presents a method of rapid assessment of the reliability of a complex technical system, where the components have different renewal times. Modern technologies of industry 4.0 relying on connecting industrial devices with the internet and data storage in the network bring about the possibility of automatic acquisition and storage in the cloud of the results of measurements of spray booths operating parameters. Selected parameters may indirectly indicate the cleanliness of the recuperator. An analysis of the collected results in the cloud enables remote determination of the recuperator's ability [5]. An analysis of the ability can be carried out by machine learning method [2] or fuzzy set logic [9].

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