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Ph. D. THESIS

THEORETICAL AND PRACTICAL RELATIONSHIPS OF THE EFFICIENCY INCREASE IN CLEANING OF PLASTIC CRATES AND BOXES USED IN AGRICULTURE AND FOOD INDUSTRY

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1. INTRODUCTION, THE AIM OF THE RESEARCH

The **processing hygiene** is the fundamental of the safe food production. It is known as well that the majority of losses from quality deteoration is derived from the neglecting the hygiene. The cost of the cleaning is significant but the theorem is valid, that the “hygiene costs a lot but this causes significant financial loss beyond the public health hazard in case of negligence of it”

But the ratio of the hygiene cost in the direct production cost is not a neutral question respecting to the economic production cost ratio.

The raw and processed products are transported in containers with very changeable size and type and transporting devices inside and outside of the firms for very different distances. Significant physical-, chemical- and microbiological contamination can be found on these devices causing food safety risks. Their sources are in the scenes of the food chain and the contamination adhering to it in the course of the delivery between the food chain points.

One of the important element of the sustaining the processing hygiene is the cleaning and disinfection of the holding and transportation devices.

According to the surveys the transporting and holding crates and boxes, made from plastic mainly, are the most frequently used in the agriculture and individual sectors of food industry. There are companies which use several boxes and crates in a day. 4 million units are being transported in the country continuously.

The continuous cleaning machines using several cleaning technology operations were developed for keeping clean of these large amount transporting devices in the developed production areas.

Two fundamental deficiencies are arisen in the course of the use of cleaning machines. One side is that not the most suitable cleaning material and technology parameters are applied for removing the type of the contamination and other sides the equipments operating with the modern high pressure nozzles are not able to remove the contamination from the parts shaded from the fluid sprays (break through, corrugations).

But there are possibilities to equip the given cleaning technology by using the ultrasound applied for cleaning and defatting the objects with complicated surface in other industries branches successfully

The efficiency is very important in case of high cleaning demands and high number of objects. Fundamental expectations against the high capacity crate and box washing machines in the course of the operation that the proper cleanness is provided along with the lowest specific cost.

The fundamental condition of the efficient cleaning is the optimal technology related with the quality of cleaning and expenditures directly. For the optimal technology it is to be known the followings:

- Properties of the contamination and carrying surface
- Size and type of the object to be cleaned
- The operation characteristics, influencing the measure of cleanness affect the separation of contamination directly, such as
  - Operational time,
  - Concentration and type of the cleaning agents,
  - Temperature of the cleaning solution,
  - Type and distance of the high pressure nozzles,
  - Pressure of the fluid streaming out from the nozzles.

In the course of my research work I have studied which type of relationships are between the cleaning agents and energy use among the cleaning operation parameters at the removing the characteristic contamination on the most frequently used applied transporting devices. I have set up the operational sequences and parameters of the technology reaching the necessary and enough measures of the cleanness using the least amount of energy for a given contamination type.

All important technical characteristic of the operation can be determined with the help of these figures and these serves as fundament for the planning and production of the washing machine.

The investigations were carried out in the laboratory of the Department of Engineering and Environmental techniques of the Faculty of Engineering of the University of Szeged.

The cleaning process elaborated on the base of the results was controlled and evaluated in industrial circumstances with an experimental washing machine made for this special aim. The equipment and test investigations are provided the Contex Műszaki és Technológiai Mérnöki Iroda, Szeged.

The aims of the research

- Elaboration of an investigation and measuring method for determination the cleaning efficiency expressing the measures of cleaning.

- Carrying out relationship investigations on the base of results of laboratory model and industrial investigations: cleaning quality (cleaning efficiency) and operational parameters for selected types of contamination,
- With the applying of ultrasound increasing the efficiency of the intensive operation phase of the cleaning technology on the base of laboratory and industrial experiment,
- Determination of the operational sequence of the optimal cleaning technology suitable for removing different kind of contamination from the plastic crates and boxes, minimising the specific costs and fulfilling the hygienic requirements.
- Determination of the operational characteristics and technical parameters with the help of the investigation results serving a fundament for the planning and operation of an efficient multipurpose washing machine,
- Equipping an experimental washing machine for the evaluation the experimental results,
- Constructing proposals for the industrial practice, for planning and operating optimal cleaning technology.

2. Materials and Methods

2.1. The aims of the investigations

The quality of the cleaning is influenced by operational parameters directly affecting the separation of the contamination in case of a selected cleaning method is influenced these are the followings:

- **Operational time (t),**
- **Temperature of the cleaning solution (ϑ),**
- **Pressure of the solution streaming out of nozzles (p),**
- **Type and concentration of the cleaning agents (D, K).**

The operational parameters closely related with the material and energy used in the course of the cleaning process
If the amount of them is known then their costs can be calculated as well.

The quality of cleaning is characterised by the efficiency of the cleaning in the course of the investigation. The measures of the expenditures are mirrored in the specific cleaning cost.

The efficiency of cleaning (η)

A measure has to be introduced for the determination of the cleaning quality, the measures of the removal of the contamination, showing the amount of removed contamination in the course of the cleaning clearly. It has to be measured as well.
IN case of a cleaning process prolonging for a time (t):

If m_o = the original amount of contamination

And m = the amount of contamination remaining after the cleaning process

Then the amount of separated contamination after time (t) is: m_o-m
If it is compared to the original value (m_o), the efficiency of cleaning is given by (1):

$$\eta = \frac{m_0 - m}{m_0} \leq 1 \tag{1}$$

The investigation has to be directed in such a way how the cleaning process parameters affect the contamination separation and cleaning efficiency for a given contamination type and cleaning method

Specific cleaning costs (K_{Tfajl})

The knowledge of the unit cleaning cost is important, so the specific cleaning cost has to be determined. It means that:

$K_{TÖ}$ = Total sum of the cleaning cost for a unit time (Ft)

P_T = Number of cleaned devices for a unit time (db), cleaning capacity

Then:

$$K_{Tfajl} = \frac{K_{Tö}}{P_T} \tag{2}$$

The aim of the investigations is to determine the direct relationships among the individual operational parameters and the two efficiency determi9nign parameters cleaning efficiency and specific cost.

2.2. SELECTED EQUIPMENTS AND CONTAMINATION TYPES

The investigations were carried out with crates and boxes having same 395 x 595 mm base and different height and with three kind of contamination. All three contamination type can be removed very hardly but their properties differed fundamentally from each other.

- **Milky** contamination ($SZÉ_1$)
  Quickly deteriorating, strong adhering to the surface, dried on. It can be contained soil, dust and mud.
- **Meaty** and **poultry** contamination ($SZÉ_2$)
  Quickly deteriorating, hydrophobic (blood, fat), adhering to the surface, it can be contained crock, smoke and dust.
- Contamination deriving at the transport of **agricultural** raw materials
  I t can be contained dried soil, dust, plant fluids and oils. (SZMg).

2.3. INVESTIGATION METHODS

2.3.1. High accuracy mass measurement for the determination of cleaning efficiency

For the measurements necessary number of samples with same size (200 x 100) of the crates and boxes to be cleaned dipped into the suspension of contamination. The mass of the crate and box samples were measured in uncontaminated state and before and after cleaning in dry state with an accuracy of 0.01 g with laboratory scale. 3 types of the contamination test suspension, mentioned in 2.2 ($SZÉ_1$, $SZÉ_2$, SZMg) were produced.

The cleaning efficiency according to the (1):

$$\eta = \frac{m_0 - m}{m_0}$$

The mass of the separated contamination (m_o-m) and the mass of the original contamination (m_o) can be measured as follows:

$$m_o - m = M_0 - M \text{ and}$$

$$m_o = M_0 - M_t \text{, where}$$

Mo	total mass of the contaminated sample [g]
M	Total mass after cleaning [g]
M_t	Mass of the uncontaminated and clean sample

In the course of the investigations of the experimental equipment a real contaminated objects were cleaned. In this case the investigated crates and boxes were signed and measured before cleaning (M_o) and after cleaning (M). The separated contamination (m_o-m) was determined in this way. For the determination of the mass of original contamination (m_o) – which is the mass difference between M_0-M_t – the total amount of contamination was removed from the signed sample after cleaning, so the mass M_t can be obtained.

2.3.2. Changing and constant parameters during the investigations

- D The type of the cleaning agent
- K Concentration of the cleaning solution (volume %)
- t cleaning time (s)
- ϑ Temperature of cleaning fluid (°C)
- p Pressure of the cleaning fluid at the nozzles (MPa; N/cm^2)
- q Volume stream of cleaning fluid (dm^3/min)
- φ Spraying angle of the fluids streaming out from the nozzle (°)

Constant parameters:

- Distance between the nozzles and the objects to be cleaned,
- Distance between the ultrasound radiating element and objects to be cleaned.

2.3.3. Mathematical method of the visualisation of measuring results

The functions fitted with the method of least squares on the results of different experimental series. The error (ε) of average-standard deviation fixed on 5%, so the correlation coefficient

(r) and determining coefficient (r^2) of the function of the investigation results are valid for 95% confidence level ($1-\varepsilon$).

The calculations were carried out with Non-linear estimation of the program package Statistica@ 6.0 of Statsoft (USA).

The program was run on personal computer configuration.

2.4. EQUIPMENTS USED IN LABORATORY INVESTIGATION

2.4.1. Experimental equipment for investigation of high pressure nozzles

Laboratory equipment was created for determination of geometry measures and measurement of the operational parameters for the type of nozzles. The equipment are shown on fig 1 (process flow) and fig 2.

Legends for process flow:

1. Water container ($V = 0.15\ m^3$),
2. Cleaning solution,
3. Suction - basket,
4. Vacuum manometer (type: TGL, measuring region: $0–1 \cdot 10^5$ Pa),
5. Pump BMS 12/36 n= 2880 rev/min, H = 110 m),
6. Manometer (Type OHM 1/1-80, MSZ 584, measuring region: $0-12 \cdot 10^5\ Pa$),
7. By-pass control (ball valve 1 1/4"),
8. Plastic crate,
9. Manometer (Type OHM 1/1-80, MSZ 584, measuring region: $0-12 \cdot 10^5\ Pa$),
10. Flexible connection,
11. Nozzle,
12. Plastic tube (∅ 1”).

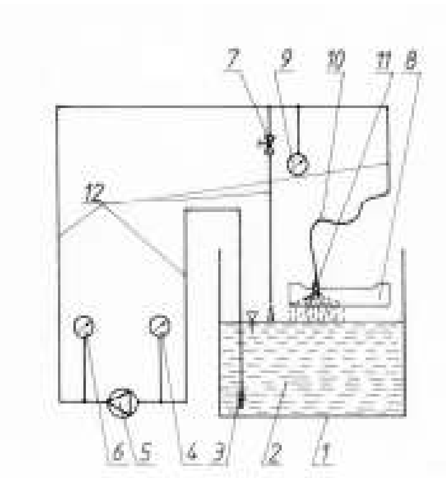


Figure 1 Process flow of the laboratory equipment

Figure 2 Experimental laboratory equipment

2.4.2. Equipment used for ultrasound investigations

A laboratory ultrasound unit (TESLA UG 160/320 TA, Czechoslovakia) was used for the measuring the ultrasound operational parameters. The equipment consisted of a container with a net volume of 12 dm^3 and high frequency ultrasound generator, which actuated piezo-electric radiators with 25 kHz at 160 or 320 W power. Taking into account the efficiency of transformation 1.3 and 2.8 Watt/dm^3 net power density can be attained in the vicinity of the object to be cleaned **(Fig 3)**

Figure 3 Ultrasonic laboratory cleaning equipment TESLA UG 160/320 TA

2.5. EQUIPMENT USED IN INDUSTRIAL EXPERIMENTS

The effective cleaning technologies elaborated on the base of research results were tested and set up on the optimal value in industrial condition in a high capacity washing machine planned. The specific cleaning cost was determined by the measured and calculated material and energy balances.

The equipment were planned and produced by the Context Mérnöki Iroda according to the special requirements as follows:

- Suitable for multitask use. Suitable for crates and boxes in different size and with different contamination,
- The technology involves a soaking intensive washing and rinsing stages,
- The intensive washing stage involves an ultrasound cleaning,
- The operational parameters are variable between certain limits
- Easy to use and highly automatised,
- Avoid the deficiencies of the earlier known type of washing machines.

2.5.1. Elaboration of instrumented fluid treating and moving system

In the course of the construction of the individual units of the washing-cleaning system the first rank planning aim was the variability of the cleaning parameters and providing the sparing operation beyond the effective cleaning.

Therefore the pre-washing-soaking the intensive cleaning and rinsing stages were equipped individual water treatment and fluid moving system. All three systems returned the used water. They require water, steam, electricity supply and canalisation.

Planning aspects of the operation

- The fluids were heated by steam on the required temperature. Direct steam injection were applied in the pre-washing and rinsing stage, the steam is mixed with the fluid in the circulating tube in the ultrasound (later on US) washing basin because of saving the cavitation space,
- The temperature and the level of the fluid are controlled by sensors and magnet ventils **(Figure 4)**,
- Both automatic and hand operation were applied,
- The units were equipped with effective sieves for saving the nozzles,
- The pressure of the fluid entering into the nozzles was changed by the by-pass control of the pumps. Because the amount of the fluid in the fresh water rinsing in the rinsing stage created a surplus continuously, therefore the by-pass line of the pump pressure side were directed into the pre-washing stage,
- A steam suction were applied because of the high fluid temperature and large number of nozzles,
- The chemicals were added by a dosing pump from a common container into the pre-washing and US basin during the operation automatically **(Figure 5).**

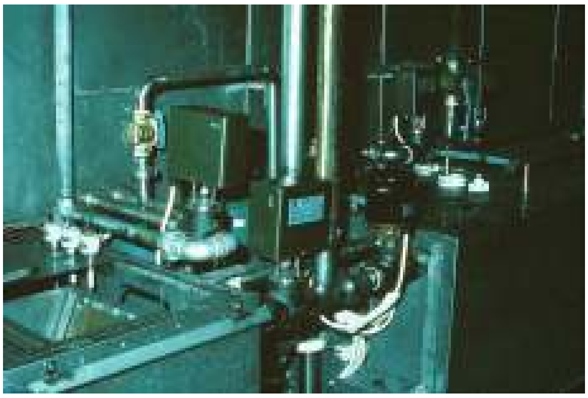


Figure 4 Level sensors and magnet ventiles

Figure 5 Membrane pumps for chemical dosage on the side containers

3. THE MAIN THESISES AND RESULTS OF THE DISSERTATION

3.1. THEORETICAL RELATIONSHIPS BETWEEN THE CLEANING OPERATION CHARACTERISTICS AND CLEANING EFFICIENCY

The result of the cleaning can be measured clearly if the dissolved or removed ratio of the original contamination is known.

Relationship between the cleaning efficiency and operation time:

Let m (t) the mass of the contamination at time "t".
The amount of the removed contamination during time of "Δt":

$$m\ (t + \Delta t) - m\ (t).$$

This amount is proportional with *Δt* and with the proportional factor and with $m\ (t) - m_v$.
Where "*a*" is a positive proportional factor expressing the efficiency of the cleaning method and the applied cleaning agent. The minus sign takes the mass decrease into account.
The m_v is the amount of the contamination remaining on the object which can not be removed from the surface by the given cleaning method.

It can be written in this way:

$$m(t + \Delta t) - m(t) = - a(m(t) - m_v)\ \Delta t \tag{3}$$

From it for m (t)

$$m'(t) = - a(m(t) - m_v)$$

A differential equation is derived, and its solution is:

$$\frac{m'(t)}{m(t) - m_v} = -a$$

$$\ln\ (m(t) - m_v) = - a \cdot t + C$$

$$m(t) - m_v = e^C \cdot e^{-a \cdot t}$$

Let e^C-= C-as a newer constant

$$m(t) - m_v = C \cdot e^{-a \cdot t}$$

$$m(t) = m_v + C \cdot e^{-a \cdot t}$$

If we consider t = 0 as initial condition, then

$$m(t) = m(0)$$

Where m(0) the original amount of the contamination

So $m(0) = m_v + C$

Where $C = m(0) – m_v$

So it can be written: $m(t) = m_v + (m(0) – m_v) \cdot e^{-a \cdot t}$

Because the effectiveness function according to the eq. (3) is:

$$\eta(t) = \frac{m(0) - m(t)}{m(0)} = 1 - \frac{m(t)}{m(0)}$$

After substitution and rearranging, and introducing

Introducing

$$\frac{m_v}{m(0)} = B \text{ sign}$$

The effectiveness function $\eta(t) = (1 – B)(1 – e^{-a \cdot t})$ can be obtained (4)

The $B = \frac{m_v}{m(0)}$ ratio shows, the remaining part of the original contamination, the (1 – B) expresses the removed part of it.

The effectiveness function is asymptotic and never reaches the 1. So certain amount of contamination is always remaining on the surface in case of the known cleaning operations.

Assuming an ideal case of $m_v = 0$, there is no remaining contamination

$\eta(t) = 1 – e^{-a \cdot t}$ can be obtained. (5)

The effectiveness vs. time function can be depicted as an exponential asymptotic function.
The ***„a”*** constant gives the dynamic of the exponential approximation, expressing the chemical effect deriving from the quality and concentration of the cleaning agent. It shows the speed of the separation of the contamination and appearing in the slope of the asymptotic curve.
The cleaning effect increases in the beginning of the treatment sharply and then decrease and finally approximate limit 1.
It can be stated from it that the **increase of the treatment time results only small cleaning effect increase after a definite limit.**

Relationship between the cleaning efficiency and temperature

The relationship can be explained by the kinetic heat theory.

The increased kinetic energy of the molecules increases the mutual interaction of the molecules, resulting the speeding up of the physical-chemical processes, and the cleaning efficiency is increased.

The kinetic energy of $\boldsymbol{m_M}$ mass, containing ***N*** molecules at temperature of ***T, is:***

$$E_{kin} = C(N; m_M)T \tag{6}$$

Where ***C*** is constant and ***T*** is the absolute temperature on the first power.

Because there is a linear relationship between the energy and temperature regarding to the changes in affectivity, the following relationship can be written:

$$d\eta_{\vartheta} = A \cdot d\vartheta \tag{7}$$

Where factor ***A*** takes into account the quality and concentration of the cleaning agent beyond the constant ***C***. The temperature is changed within the characteristic range of the cleaning agent, expressed in °C.

Integrating eq. (7) and applying the boundary conditions it can be written:

$$\begin{aligned} &\vartheta = \vartheta_0 \quad ; \quad \eta = \eta_a \\ &\eta_{\vartheta} = \eta_a + A(\vartheta - \vartheta_0) \end{aligned} \tag{8}$$

Where η_a is initial value of the efficiency of the cleaning agent at normal temperature e.g. at room temperature (ϑ_0).

3.2. CHOOSING THE NOZZLES AND CONTROL OF THEIR STREAMING CHARACTERISTIC

3.2.1. Point of view of the choosing

The distance of the nozzles from the surface to be washed is changing at one crate/box too. The outer surfaces receive the washing fluid closer distance (100 mm), than the inner surfaces farer distance (150–400 mm). In the first case nozzle with large spraying angle is the proper choice **(Figure 6)**, meanwhile narrower spraying angle is more suitable in the second case **(Figure7).**

At the Department of the Mechanisation and Process Control of the College of Food Engineering a nozzle family has been developed for different washing, cleaning in 80-ies, which build up from a series of nozzles spraying straight line and in a definite angle.

On the Figure 6 a nozzle can be seen which diverts the stream with a 75° angle creating a broad fluid stream. An another type of nozzle can be seen on Figure 7 which create a narrow fluid stream having enough impulse power at 300-400 mm distance. The showed types were developed for the experimental equipment at the College of Food Engineering.

Nozzle with flat spraying pattern can be seen on the figures. Its advantage is that they concentrate the stream on small area. This type of nozzle can be applied because the surface to be cleaned and the transporting device are moving relative to the standing nozzles during the cleaning. We had to pay special attention on the surface roughness because the rough surface distorts the spraying pattern.

The fluid circuits have to be set up according to amount of fluid streaming out from all nozzles in the washing equipment (container, pump, pipeline, and sieve). Therefore the volume stream, spraying pattern and spraying angle of the chosen nozzles has to be known in dependence on the pressure.

On the base of the a priori rating the volume stream nozzles has to be chosen which fulfil the following streaming characteristics.

Fluid streams at pressure of $2 \cdot 10^5$ Pa

Pre-rinsing I. stage and in the freshwater after rinsing $q_1 = 3.2\ dm^3/min$

Pre-rinsing II. Stage and in the freshwater after rinsing $q_2 = 6.4\ dm^3/min$

Pre-rinsing III. Stage and in the freshwater after rinsing $q_3 = 9.6\ dm^3/min$

Spraying angles at pressure of $2 \cdot 10^5$ Pa

$\varphi_1 = 120$ °(nozzle with flat pattern, surface striking type)

$\varphi_2 = 50°$ (Nozzle with flat pattern, fluid striking type)

So the equipment required two types of nozzle with three inner measures.

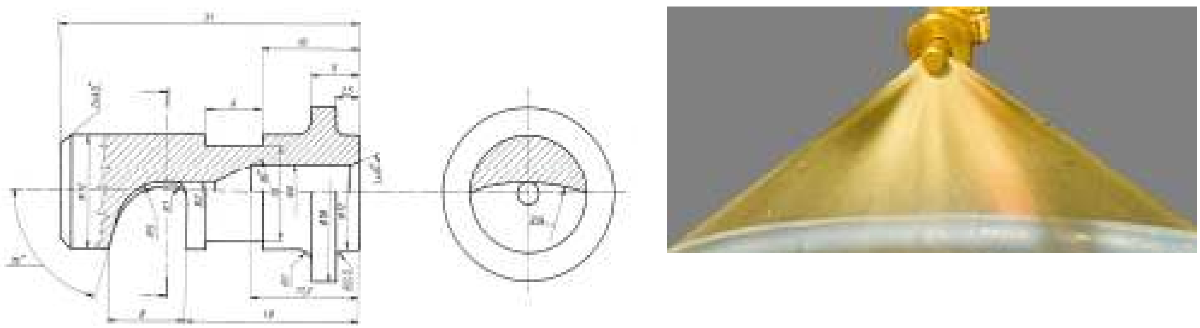


Figure 6 Technical drawing and spraying pattern of the large spraying angle nozzle (type K–2/75 surface striking)

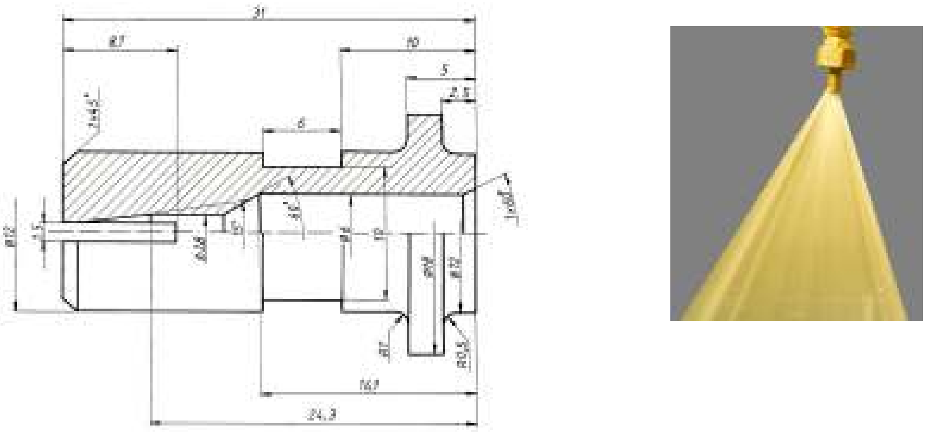


Figure 7 Technical drawing and spraying pattern of the narrow spraying angle nozzle (type 2.8/1.5)

3.2.2. Development of the volume stream and spraying angle in dependence of pressure

In case of the chosen 2x3 nozzles I have tested the expected streaming characteristics (φ, q) with measurements between certain pressure limits **(Figures 8, 9, 10)**. The measurements had carried out in laboratory equipment under the following conditions.

Chosen nozzles:

Fluid striking:	E-2/1	Surface striking diverting 75°:	K-2/75
	E-2.8/1.5		K-2.8/75
	E-3.6/1.7		K-3.6/75

- Material of the nozzles SRA58
- Characteristic of the streaming fluid: clean, communal water at ambient temperature
- Pressure range: 1,5-3 x 10^5 Pa overpressure

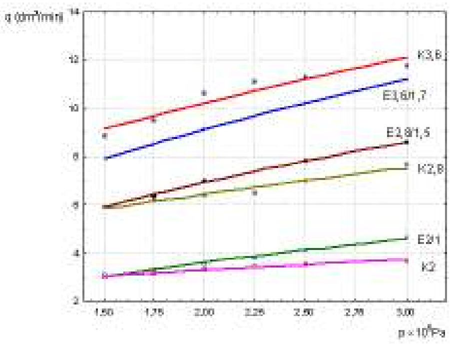


Figure 8 Combined graphs for nozzle volume stream vs. pressure

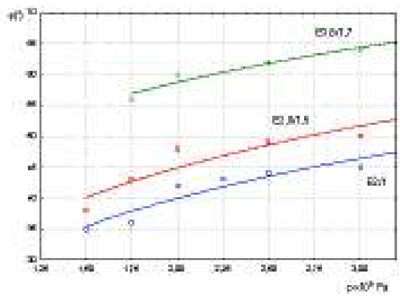


Figure 9 Development of the spraying angle of the fluid striking nozzles vs. pressure

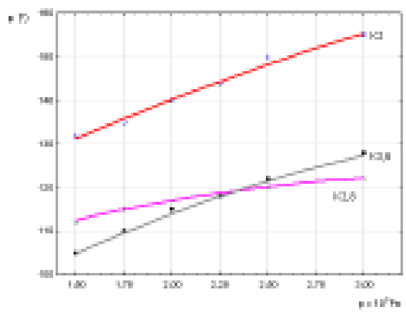


Figure 10 Development of the spraying angle of the surface striking, flat spraying nozzles vs. pressure

3.3. MODEL EXPERIMENTS FOR INVESTIGATION OF THE OPERATION PARAMETERS OF ULTRASOUND CLEANING VIZSGÁLATÁHOZ

I determined the highest cleaning efficiency for the operation time and cleaning agent temperature range. I applied test contamination and cleaning agents with and without ultrasound for comparison. Beyond these the combinations of them were studied as well.

3.3.1. Efficiency of cleaning in dependence on time

The experiments were carried out in ultrasound laboratory equipment under the following conditions:

- Operational time region: 5-60 sec.
- Cleaning solution: 1% NaOH
- Solution temperature: 65 °C
- Test contamination: dried on, milky
- Investigated surface: plastic crate
- Ultrasound generator power: 320 Watt
- Ultrasound frequency: 25 kHz

The efficiency values belonging to the given treatment time are shown on Figure **11** with (η_{UH}) and without ultrasound.

The latter one corresponds to the soaking with cleaning agent (η_A). An asymptotic function can be fitted on the measurements results according to the eq. 4.

Where:

$$\eta_{UH} = 0.93 \times (1 - e^{-0.14\,t})$$

$$r^2 = 0.95$$

$$\eta_A = 0.72 \times (1 - e^{-0.05\,t})$$

$$r^2 = 0.93.$$

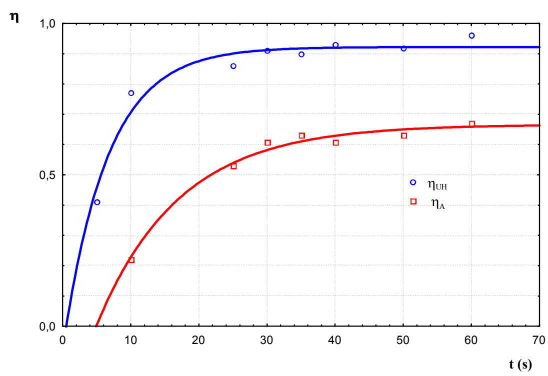


Figure 11 Development of the cleaning efficiency vs. treatment time

3.3.2. Cleaning efficiency in dependence on temperature

The experiments were carried out with the same conditions described in 3.3.1 but with some alterations as follows:

- Cleaning solution temperature region: $\Delta\vartheta = 20 - 65°C$
- Operational time: t = 60 sec, constant.

The results of the investigations are shown on Figure **12**:

$$\eta_{UH} = 0.607 + 0.005\,\vartheta$$
$$r^2 = 0.9265$$

$$\eta_A = 0.63 + 0.007\,\vartheta$$
$$r^2 = 0.9563.$$

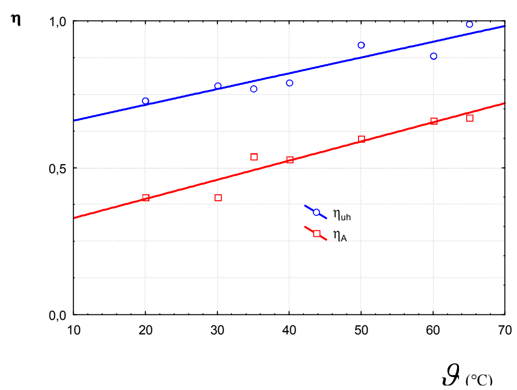


Figure 12 Development of the cleaning efficiency vs. temperature

3.3.3. Cleaning efficiency in dependence on the time, in case of combined treatment

The experiments were carried out with the same conditions described in 3.3.1 but with some alterations as follows:

- - Cleaning solution temperature: ϑ 60°C, constant
- - Operational time: 0-30 sec without ultrasound radiation (soaking) between 30-60 sec with ultrasound radiation.

$$\eta_{komb} = 0.72 \text{ x } (1 - e^{-0.05\,t}) + k\,0.93\,(1 - e^{-0.14\,(t-30)})$$
$$r^2 = 0.9637$$

Where $k = 0.2686$

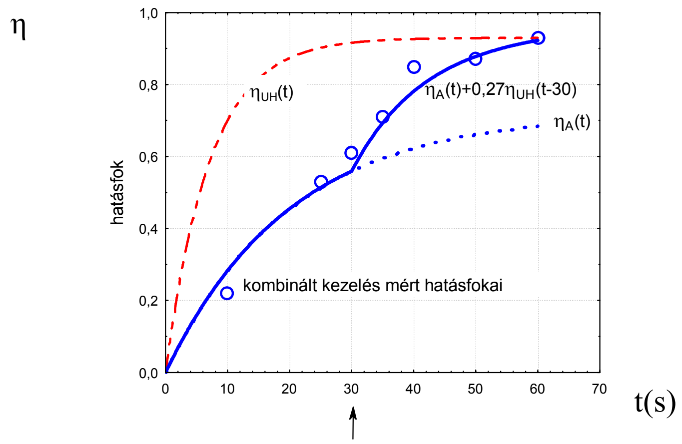


Figure 13 Development of the cleaning efficiency vs. time in case of combined treatments

Summarising the investigation results we can state, that the time and the temperature, between certain limits, taking the cleaning agent property and its concentration as constant, and the cleaning efficiency function is increasing and approximates a maximum value.

The theoretical relationships were proved by the investigation results relating to the treatment time and cleaning efficiency. An asymptotic curve can be fitted on the measured. A linear relationship can be shown between the temperature and efficiency as expected from the theoretical conclusions.

A strong adhering contamination, such as dried milk on the surface, can be removed with the use of low concentration of cleaning agent (1%NaOH) and ultrasound treatment within 50-60 sec.

The efficient cleaning agent temperature is 55-65°C, as for the optimum temperature range of cavitations.

This two stage cleaning operation is very useful guidance for the practical application of the operation. A properly chosen soaking cycle shortens the time of the intensive cleaning phase requiring more energy.

3.3.4. Development of the cleaning efficiency in dependence of time at different distance from the radiation source

I have studied the cleaning efficiency of the object to be cleaned at longest (300 mm) and shortest (20 mm) distance from the radiating heads in the experimental washing machine.

The experiments were carried out in ultrasonic laboratory equipment under the following conditions:

- Test contamination: dried on soil, mud,
- Investigated surface: plastic crate,
- Cleaning fluid: communal network water,
- Fluid temperature: 40°C, constant,
- Operation time region: 10-60 sec,
- Ultrasound generator power: 320 W,
- Ultrasound frequency: 25 kHz,
- Average power density: 2 W/cm$^{3.}$

The efficiency vs. time relationship is shown on Figure **14**.

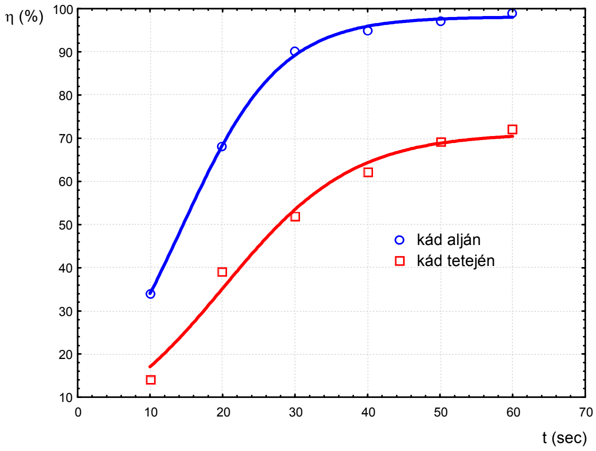


Figure 14 Development of the cleaning efficiency vs. time in case of combined treatments at different distance from the radiation source

It can be seen that the surfaces situated at 20 mm distance were cleaned with a good efficiency in case of 30 sec; meanwhile the efficiency is only 50% for the surfaces in 300 mm distance. The larger distance means always the inner bottom of the crate or box. Therefore it is very important to loose up of the contamination on it in the pre-soaking stage before the intensive cleaning.

3.4. INVESTIGATION OF ULTRASONIC CLEANING OF CRATES AND BOXES WITH FOODCONTAMINATION

3.4.1. Choosing the proper cleaning agent for milky contamination for ultrasonic treatment

7 different cleaning agents had been investigated in the proposed concentration.

The experiments were carried out in ultrasonic laboratory equipment under the following conditions:

- Contamination type: dried on, milky,

- Investigated surface: plastic crate,
- Cleaning solution: communal network water + 7 pre-chosen cleaning agents type,
- Solution concentration: vol. % given by the producer
- Solution temperature: 60°C, constant,
- Operational time: 60 sec, constant.

The investigation results are shown on Figure **15.**

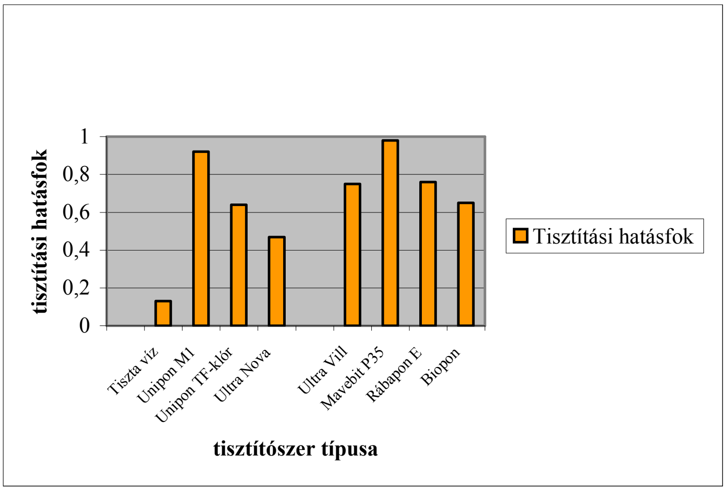


Figure 15 Effect of different cleaning agents on plastic crates with ultrasound treatment

3.4.2. Relationship between treatment times, solute concentration and largest efficiency at three different temperatures

According to the investigation showed in 3.4.1 the MAVEBIT P35 proved as best ($\eta \geq 98$) among the chosen cleaning agent applying the same operation parameters. Therefore it had been investigated which combination of the three most important parameters (t, K, ϑ) can be achieved this maximal value. The parameter combination relationships give orienting figures for the determination of the optimal cleaning technology and for the planning of the equipment.

The experiments were carried out in ultrasonic laboratory equipment under the following conditions:

- - Contamination type: Milky
- - Investigated surface: plastic crate
- - Cleaning agent: MAVEBIT P35
- - Solution concentration region: 1,5-3 vol. %
- - Solution temperature: 50, 60, 70 °C
- - Operation time region: 0-110 sec

The measuring results and their functions are shown in Figure **16.**

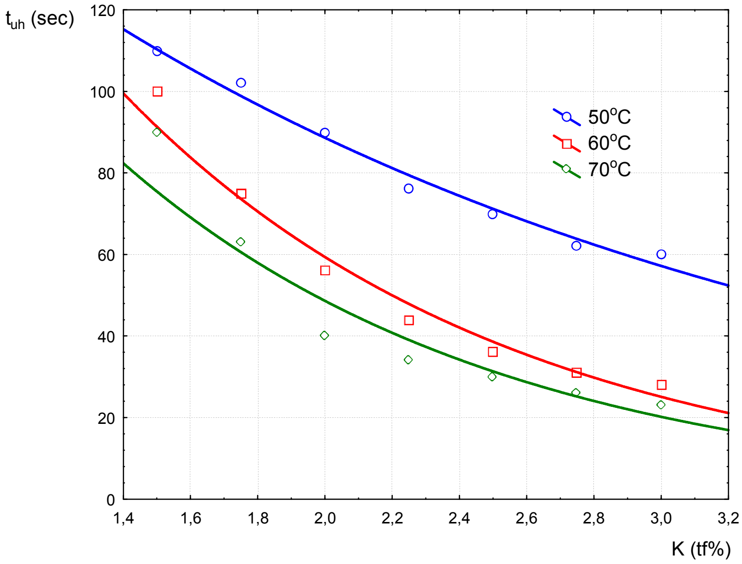


Figure 16 Treatment times belonging to the highest efficiency vs. solution concentration at three different temperatures

It can be stated with help of the figure 16 that which combinations of cleaning agent concentration temperature and operation time give the best cleaning efficiency in the ultrasonic cleaning under the experimental conditions mentioned before.

3.4.3. Choosing the efficient cleaning agent of meaty contamination in ultrasonic treatment

The investigation conditions are the same as mentioned in 3.4.1. Here ULTRA cleaning agent were used instead of BIOPON, the test contamination was meaty.

The effect of the cleaning agents is shown on figure 17.

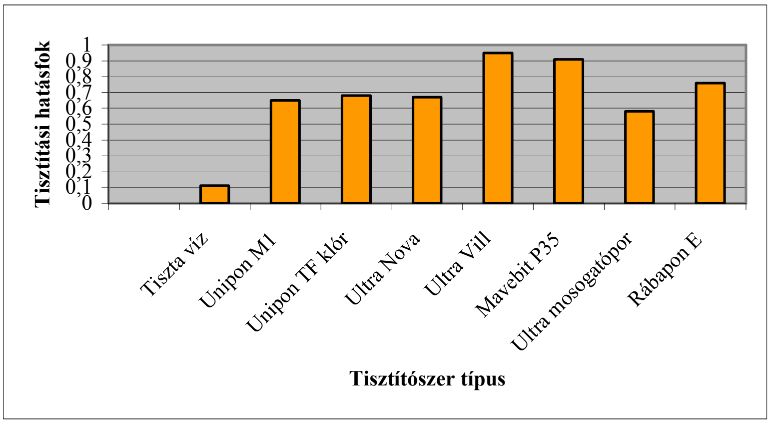


Figure 17 Investigation of cleaning effects of different cleaning agents with ultrasound

3.5. FLUID STREAM (NOZZLE) CLEANING OF FOOD CONTAMINATED CRATES

Fluid stream (nozzle) cleaning methods were planned in the stages of pre-washing, soaking, rinsing I. and rinsing II among the cleaning technology operation. Because the rinsing I. and rinsing II stages have no cleaning effect, therefore the experiments were focused on the determination of the operation parameters of the pre-washing and soaking stages. The water, cleaning agent and heating energy consumption are the highest in this stage. Holding on the cleaning parameters on the optimal values is the most important for the economic operation. The crates and boxes were investigated separately because of their different surface. The investigations were carried out according to combined treatment (chapter 3.3.3.) at constant (55°C) cleaning solution temperature and at constant 30 sec half treating time.

3.5.1. Development of the cleaning efficiency in dependence on the cleaning solution pressure and concentration for milky contamination

The investigations were carried out in fluid stream (nozzle) laboratory equipment under the following conditions:

- Type of the contamination: Milky,
- Investigated surface: inner and outside of the plastic crate, box,
- Type of the cleaning agent: MAVEBIT P35,
- Solute concentration: variable, 0; 0,5; 1; 1,5; 2 vol. %,
- Solution temperature: constant: 55°C,
- Operational time: constant: 30 sec,
- Nozzle distance: 200 mm,
- Fluid pressure: variable 2 ; 3 x 10^5 Pa,
- Nozzle type: E-2.8/1.5.

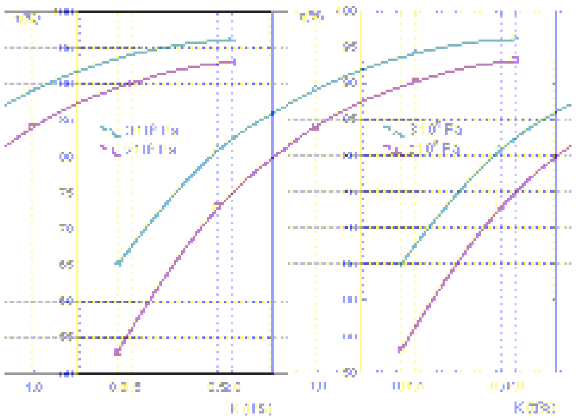


Figure 18 Development of the cleaning efficiency vs. cleaning solution pressure and concentration at the inner side of the crate

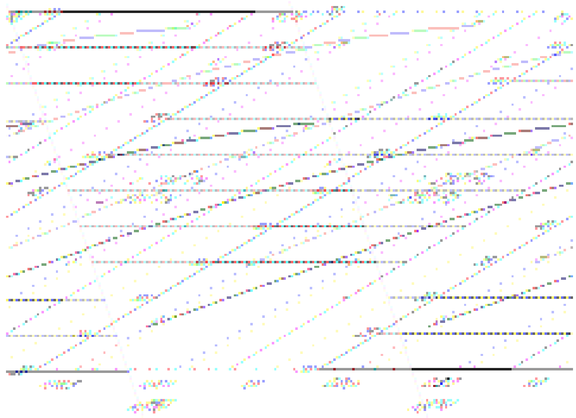


Figure 19 Development of the cleaning efficiency vs. cleaning solution pressure and concentration at the outer side of the crate

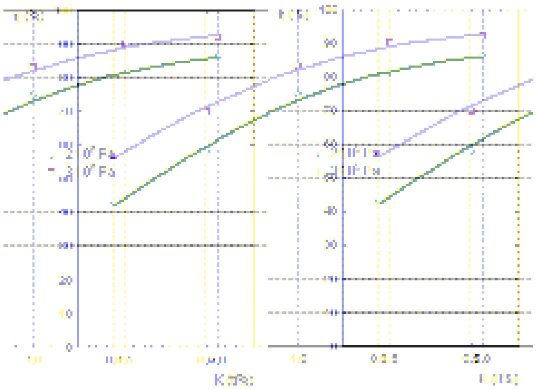


Figure 20 Development of the cleaning efficiency vs. cleaning solution pressure and concentration at the inner side of the crate

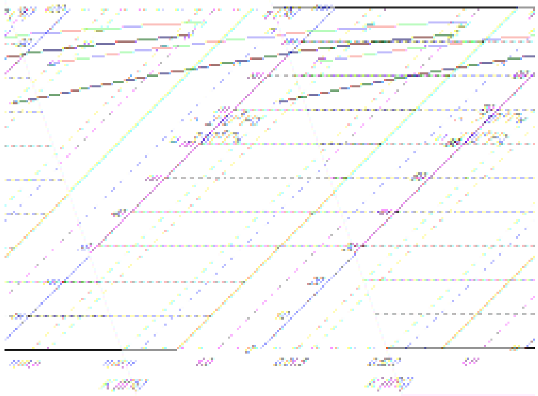


Figure 21 Development of the cleaning efficiency vs. cleaning solution pressure and concentration at the outer side of the crate

The characteristic parameters of the pre-washing operation can be given for the following limits and MAVEBIT P-35 cleaning agent on the base of the experiments carried out with nozzles (diameter of 2,8 mm) and nozzle distance of 200 mm-:

- Temperature of the solution: 50-60°C
- Solute concentration: 1-2 vol. %
- Pressure of the fluid streaming out: $2-3\cdot 10^{5}$ Pa
- Operational time: 30-40 sec

3.5.2. Development of cleaning efficiency in dependence on the pressure and concentration of cleaning solution in case of meaty contamination

The investigations were carried out in fluid stream (nozzle) laboratory equipment under the following conditions:

- - Type of contamination: meaty,
- - Investigated surface: inside and outside of the plastic crate and box,
- - Type of cleaning agent: ULTRA VILL,
- - Solute concentration: variable, 0; 0,1; 0,2; 0,3 vol. %,
- - Temperature of the solution: constant: 55 °C,
- - Treatment time: constant: 30 sec,
- - Distance of the nozzle: 200 mm,
- - Fluid pressure: variable 2 ; 3 x 10^{5} Pa,
- - Type of nozzle: E-2.8/1.5.

The results of the investigation are shown on Figure **22, 23, 24, 25.**

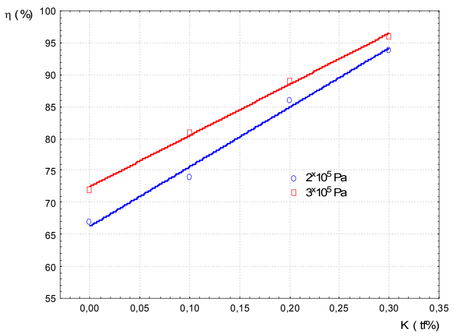


Figure 22. Development of the cleaning efficiency vs. cleaning solution pressure and concentration at the inner side of the crate

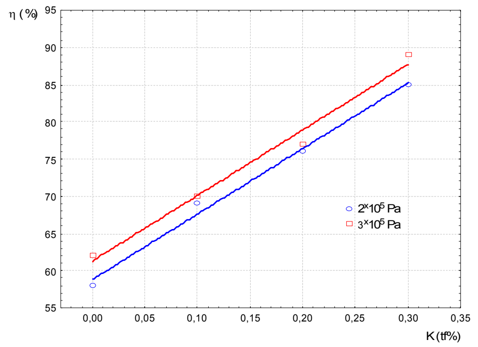


Figure 23 Development of the cleaning efficiency vs. cleaning solution pressure and concentration at the outer side of the crate

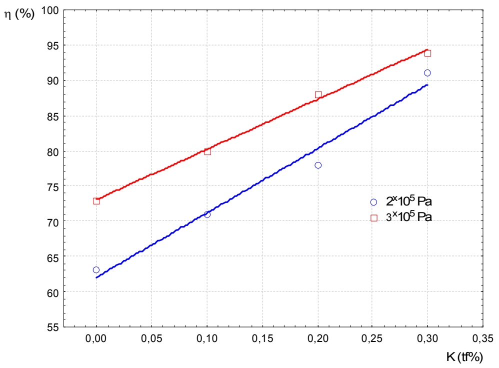


Figure 24 Development of the cleaning efficiency vs. cleaning solution pressure and concentration at the inner side of the crate

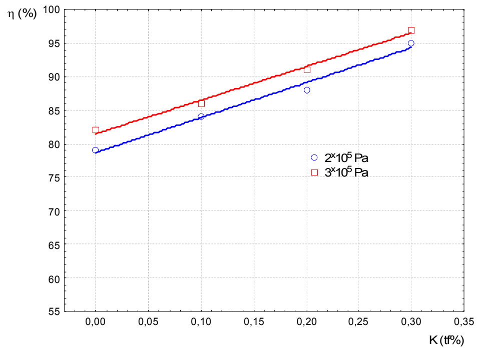


Figure 25 Development of the cleaning efficiency vs. cleaning solution pressure and concentration at the outer side of the crate

3.5.3. Evaluation of the fluid stream (nozzle) investigations

The experiments showed that the significant part of the contamination can be removed without cleaning agents at pressure of $2-3\cdot10^5$ Pa. The intensive washing operation is well prepared by the nozzle cleaning at pressure of $2\cdot10^5$ Pa and at the lower level of the proposed cleaning agent concentration. Contaminations remained only in scraped outer parts of the crates and corrugations shaded from the nozzle fluid stream. It has to be removed by the cavitations fluid space.

The nozzle distance was 200 mm. From the higher cleaning efficiency values can be concluded that most of the contamination can be removed and the loosening of the contamination remaining on the surface has been occurred for any size of crates or boxes in the washing frame.

A good cleaning efficiency could be achieved by the ultrasonic cleaning and nozzle pre-washing experiments within the applied parameter region. A really effective cleaning can be expected by the combination of them in real industrial conditions as well.

3.6. INVESTIGATIONS OF THE FLUID STREAM (NOZZLE) CLEANING OF PLASTIC CRATES USED IN THE AGRICULTURE

For determining the optimal technology the 3 most important parameters (t, p, ϑ) were varied in case of fluid stream (nozzle) cleaning. Furthermore it was investigated whether the use of the ultrasonic cleaning, as intensive operation stage, and the cleaning agents can be neglected or not.

The investigation was carried out with network water. The contamination of crates and boxes coming from the agriculture was mainly fresh or dried on soil, mud, perhaps lumpy contamination, vegetable and fruit rests. This is not hydrophobic, water repellent. Therefore the cleaning effect without cleaning agent was investigated in higher pressure range as well, which is suitable for removing the contamination with large impulse power after loosening.

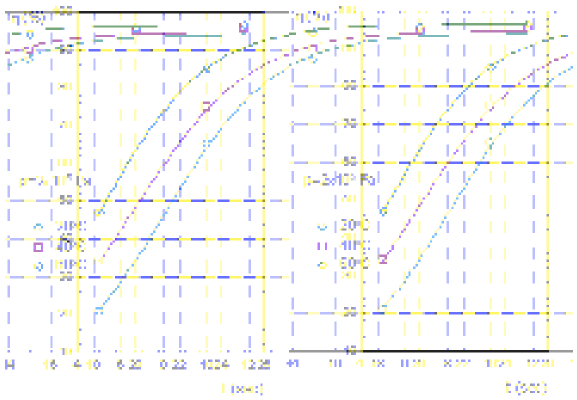
3.6.1. Development of the fluid stream (nozzle) cleaning efficiency in dependence on the operation time at different temperature and pressure without cleaning agent

The investigations were carried out in fluid stream (nozzle) laboratory equipment under the following conditions:

- - Type of test contamination: soil and mud dried on
- - Investigated surface: plastic crate
- - Cleaning fluid: Communal network water
- - Fluid temperature: 20; 40; 60°C
- - Fluid pressure: 2, 4, 8, 10 x 10^5 Pa
- - Treatment time: variable: 0-25 sec
- - Distance of the nozzle: 200 mm
- - Type of nozzle: E-2,8/1,5

The investigation results are shown on Figures **26, 27, 28, 29.**

A $y = C (B + e^{-at})$ type exponential function were fitted on the investigation results.



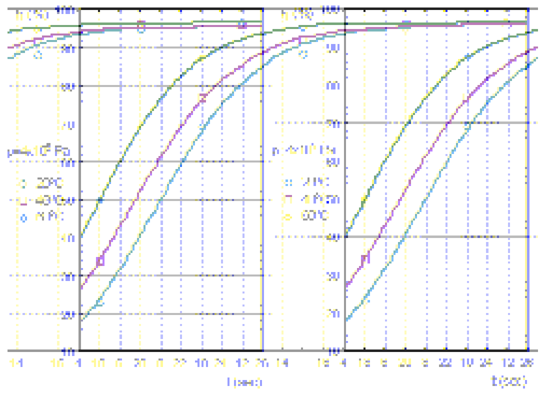
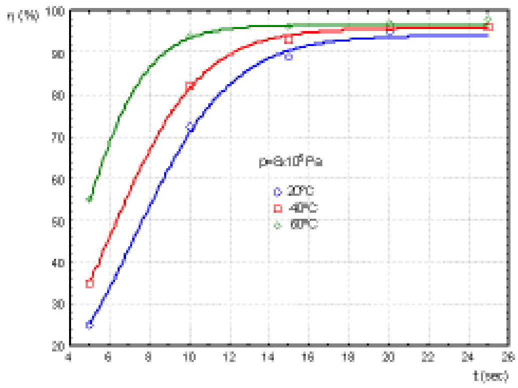


Figure 26 Development of the cleaning efficiency vs. operational time at different temperatures and at $2x10^5$ Pa pressure

Figure 27 Development of the cleaning efficiency vs. operational time at different temperatures and at $4x10^5$ Pa pressure



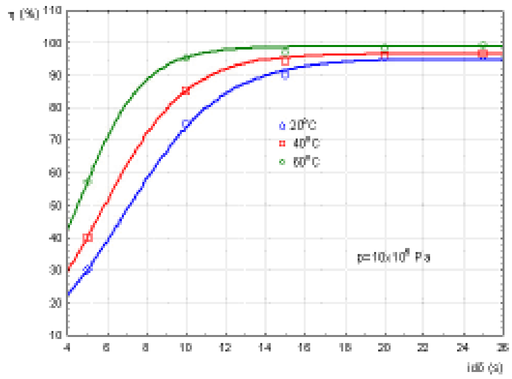


Figure 28 Development of the cleaning efficiency vs. operational time at different temperatures and at $8x10^5$ Pa pressure

Figure 29 Development of the cleaning efficiency vs. operational time at different temperatures and at $10x10^5$ Pa pressure

3.6.2. Evaluation of the fluid stream (nozzle) investigations

The results showed that the pressure and temperature effect is valid till only treatment time of 15 sec in case of cleaning of the crates with contamination of agricultural origin clearly, and then the cleaning efficiency is improved very little. It is very important information for the planning of the technology operation that the effect of the cleaning solution at a pressure of 10 x 10^5 Pa and temperature of 20°C is about the same as the treatment at a pressure of 2 x 10^5 Pa and a temperature of 60°C for 15 sec.

Therefore calculations were made which operation parameter pair gives the most economic cleaning

A power index (A) was used in the calculations. The index is the ratio between the heating power used for the warming up and the power consumed by the pressure increase of the streaming fluid at the same volume stream

$$A = \frac{Heating\ power}{\Pr essure\ increase\ power} = \frac{P_{hő}}{P_{ny}} \qquad (13)$$

The comparisons were made for warming up from 20 to 60°C and pressure increase from 2 bars to 10 bars.

According to the calculations the index (A) is about 120, so about two order higher power/energy is needed for the increase of the temperature of the cleaning solution than for the pressure increase at the given parameters.

3.7. Determination of the parameters and operation sequence of the optimal cleaning technology taking into account the multitask use

The results of the investigations and the experience obtained with traditional cleaning technology showed that it is important that a soaking operation to be precede the intensive washing in case of contamination adhering strongest on the surface. The time of the intensive operation decrease significantly in this way, because only during the soaking the loosened, peptised or remaining contamination has to be removed.

Operation steps of the technology showed on the Figure **30** are suitable for removing the contaminations bounding to the surface occurring in the food industry even for crates and boxes with complicated surface on the base of the experimental results and experience.

Operation steps and their characteristics on the base of Figure **30**:

Soaking, pre-washings: it improves the efficiency of the intensive cleaning stage in a high measure. The cleaning agent at a maximum temperature of 60°C is sprayed by nozzles to the surfaces. The protein precipitation and the surface burning on of the contamination can be avoided at this relatively low temperature. In this operation stage the loose adhering and lumpy contamination can be removed and the stronger bounded ones are loosen. If the time of soaking pre-washing increases then less contamination get into the next operation stage.

Intensive cleanings: It is the ultrasonic cleaning operation. The chemical effect of the cleaning solution is combined with the mechanic effect of the ultrasound and cavitations space. The remaining part of the contamination, can be found in corners corrugations and breakthrough shaded from the nozzle spray, is removed in this stage. The temperature of the solution is held on 55-65°C which is the optimum value for development of the cavitations as well.

Rinsing I: According to the hygienic rules an efficient rinsing, separated in space, is followed the chemical cleaning. The rinsing fluid is clean and contains no detergent and it is sprayed by nozzles on the object. The temperature of it is 80-90°C so it has disinfection effect as well.

Rinsing II: If the rinsing is carried out in recirculating system it is compulsory to apply a second rinsing with drinking water.

Dewatering by blowing: The fluid on the surface of the objects has to be removed in the last stage of the technology. It is carried out with high pressure blower. The objects coming out from the hot water rinsing can be dried down by applying air at normal temperature quickly. For the full dry down a separate drying tunnel has to be connected to the washing machine where the fully dry surface is a requirement.

Cleaning agents are needed in the first two stages. Their concentration can be held by automatic dosage on the required value. Where disinfection is needed, in case of food contacting containers, the cleaning agent and disinfectant are applied together.

It can occur that the contamination of the container does not need cleaning agent. Neglecting it decreases the operation cost.

Because the contamination on the objects coming from the agriculture is not hydrophobic and water repelling the main cleaning effect has to be provided by the sweeping effect of the impulse power of the nozzle spray in the pre-washing stage.

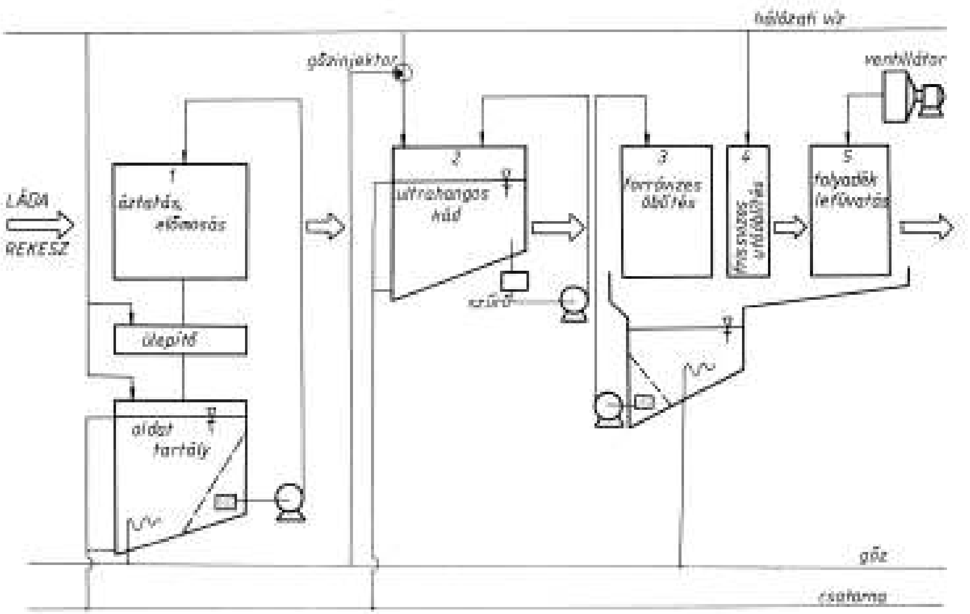


Figure 30 Operational steps of the cleaning technology suitable for removing adhering contamination arising on food crates and boxes with complicated surface

The temperature of the cleaning solutions and rinsing fluids and the operation time coming from the moving speed has to be controlled according to the measure and type of the contamination.

Taking into account that the time of the intensive cleaning is 30 sec then the pre-washing time is minimum 30 sec. The other three stages require 30 sec all together. The effective operation time of the cleaning may not shorter than 90 sec.
The above described operational and functional characteristics of the cleaning technology serve as starting point for equipment planning.

3.8. RESULTS OF THE INDUSTRIAL TEST OF THE EXPERIMENTAL EQUIPMENT

The experimental equipment set up at the Szeged site of the Contex Mérnöki Iroda for cleaning investigation. The cleaning technology was optimised for three pre-chosen critical contamination type (milky, meaty, and agricultural). Crates and boxes in different sizes were cleaned.

Table 1 Optimised operational parameters of cleaning technologies proposed for transport devices contaminated in the food industry

Operation	Fluid temperature (°C)	MAVEBIT P35 solution concentration (vol. %)	ULTRA VILL solution concentration (vol. %)	Operation time (sec)	Fluid pressure on the nozzle (p x 10^5 Pa)
Pre-rinsing soaking part	$\vartheta_{I\,max} = 45$	$K_{I\,max} = 1$	$K_{I\,max} = 0{,}1$	$t_I = 40$	$p_{I\,max} = 2$
Intensive washing part (UH 2 kW, 25 kHz)	$\vartheta_{II\,max} = 55$	$K_{II\,max} = 1$	$K_{II\,max} = 0{,}1$	$t_{II} = 30$	-
Rinsing I.	$\vartheta_{III\,max} = 80$	-		$t_{III} = 10$	$p_{III\,max} = 1{,}5$
Rinsing II	$\vartheta_{IV\,víz}$ = Drinking water temp.	-		$t_{IV} = 2$	p_{IV} = network pressure

Table 2 Optimised operational parameters of cleaning technologies proposed for transport devices contaminated in the agriculture without ultrasound

Operation	Fluid temperature (°C)	ULTRAVILL Solution concentration (vol. %)	Operation time (sec)	Fluid pressure on the nozzle (p x 10^5 Pa)
Pre-washing-Soaking stage	$\vartheta_{I\,min} = 20$	-	$t_I = 15$	$p_{I\,min} = 2$
Intensive washing stage	$\vartheta_{II\,min} = 60$	0,1	$t_{II} = 15$	$p_{II\,min} = 8 - 10$
Rinsing	$\vartheta_{III\,min} = 20$	-	$t_{III} = 10$	$p_{III\,min} = 2$
Rinsing II.	$\vartheta_{IV\,víz} = 20$	-	$t_{IV} = 2$	$p_{IV} = 2.$

3.8.1. Calculation of specific cleaning costs

The cost falling for one unit is the specific cleaning cost according to the eq. 2:

$$K_{tfajl} = \frac{K_{Tö}}{P_T} \quad \left(\frac{Ft}{db}\right)$$

The total expenditure for cleaning for unit time is:

$$K_{Tö} = E + A \quad \left(\frac{Ft}{\min}\right)$$

E – Energy
A – Material

The number of cleaned unit for a unit time is the washing capacity

$$P_T \quad \left(\frac{db}{\min}\right)$$

The results of the calculations are summarised in table **3** relating for one shift. The ratios of the stages are shown as well.

Table 3 Ratio of costs/shift in %

Nomination of material, auxiliary energy uses	Cost Ft/Shift	Ratio compared to the total cost %
Water	5 845	9,27
Electric energy	8 400	13,32
Steam	12 075	19,15
Cleaning agent	36 750	58,26
Total:	**63 070**	**100,00**

The cost composition showed that 80% of the operation cost is made up by the warming up the cleaning solution and the cost of the cleaning agent. The cost of the cleaning agent made up the 80 % of the total cost. It can be seen that it is important to hold the temperature and concentration of the solution on the optimal value.
The specific cleaning cost of technologies applied for two type of contamination is shown in Table **4**.

Table 4 Comparison of specific cleaning costs for different cleaning technologies

Type of contamination	Cleaning technology	Specific cleaning cost K_{Tspec} (Ft/pieces)
Food industry contamination	Non optimised technology	**38,50**
	Optimised technology	**27,30**
Agriculture contamination	Ultrasound technology	**23,64**
	Simplified technology without ultrasound operation	**9,37**

4. NEW SCIENTIFIC RESULTS

1. I have found and exponential asymptotic theoretical relationship between the cleaning efficiency and cleaning time:

   $$\eta(t) = (1 - B)\,(1 - e^{-at}).$$

   I have proved with ultrasonic model experiments that the cleaning efficiency of the NaOH solution at a temperature of 65°C and at the concentration of 1%increasing the operation time of 1-60 sec is changing asymptotically $y = C\,(1 - e^{-ax})$.
   The increase of the operation time does not cause significant improvement after a certain time.
2. I have found a theoretical linear relationship between the cleaning efficiency (η) and the temperature of the cleaning solution (t):

   $$\eta(\vartheta) = C + A\,(\vartheta - \vartheta_0).$$

   I have proved with ultrasonic model experiments that the cleaning efficiency of the NaOH solution at a temperature of 30-65°C and at the concentration of 1% at the same operation time of 60 sec is increasing along with temperature linearly ($y = C+Ax$).
   The temperature of cleaning solution of high cleaning efficiency is fall into the optimum temperature range of the cavitations development (ϑ = 55-65 °C).
3. I have stated that influences the cleaning efficiency of the ultrasonic cleaning without cleaning agent is influenced by the distance from the radiation source strongly: the cleaning efficiency (η) is 45% less in 250-300 mm distance (t=30s, ϑ = 40 °C) in case of contamination of agricultural origin compared to 20 mm distance.
4. On the base of the ultrasonic experimental results I have determined a relationship which determine the maximum cleaning efficiency for the treating time (t) and concentration (K) parameter pairs for milky contaminated plastic crate and for ultrasonic cleaning with MAVEBIT P35 cleaning agent at given temperatures of cleaning agent (ϑ = 50, 60, 70 °C). In this way the cleaning operation can be optimised simply because the applicable variable pairs (t, K), are on the isotherms giving the maximum efficiency.
   I have shown furthermore that the cleaning efficiency can be decreased about on the half by the choosing the improper cleaning agent compared to the right ones along with the same operation conditions.
5. I have proved by experiments that the cleaning efficiency develops exponential [$y = C\,(e^{-ax} + B)$] by the increase of the MAVEBIT P35 cleaning solution concentration (K=0-2,0%) at fluid stream (nozzle) cleaning in case of dried on milky contamination, at the same operation parameters (ϑ, t, p) meanwhile this relationship for meaty contamination and with increasing concentration of Ultra-Vill cleaning solution (K = 0–0,3%) develop linearly ($y = C + Ax$).
6. I have proved by experiments that the increase of the operation time (t = 0–25 s) of cleaning increases the cleaning efficiency exponentially [$y = C\,(B + e^{-ax})$] in case of fluid stream (nozzle) cleaning and contamination of soily agricultural origin at the same operation parameters (p, K, and ϑ).
   I have stated that the effect of the operation time prevails till only 15 sec. After it the efficiency can not be significantly improved even with the increase of the pressure (p) and temperature (ϑ) of the cleaning solution.
7. I have proved that about the same cleaning efficiency can be achieved by different temperature-pressure parameter pairs in case of fluid stream (nozzle) cleaning and contamination of agricultural origin.
   I have proved that choosing higher pressure belonging to lower temperature is more advantageous in energy use than applying the higher temperature lower pressure parameter pair.
   The increase of the temperature of cleaning solution by 1°C is needed 24 times more energy than the increase of its pressure (p) by 1×10^5 Pa at the same volume stream.

5. RESULTS APPLICABBLE IN THE PRACTICE

1. On the base of the investigation I propose that a loosening, soaking stage precede the intensive cleaning stage in case of on the surface strongly adhering, hydrophobe contamination of food origin. The so called peptisation is a chemical-physical process therefore it needs time and higher temperature of cleaning solution.
2. From the investigation can be stated that the ultrasonic cleaning has importance in cleaning the crates and boxes with complicated surfaces on which dried on hydrophobe biological contamination can be found first of all.
3. I propose that the size of the nozzle and hence the power of the fluid stream in the pre-washing stage increase continuously. The loosening the dried on contamination is needed rather time and not the sweeping effect deriving from the impulse power of the strong fluid stream.
4. I have demonstrated in the investigation of the contaminated objects deriving from agriculture clearly, that any operation parameters have no significant effect on the cleaning efficiency in case of fluid stream (nozzle) cleaning after 15 sec. In this way shorter lengths of the stages are needed. The price of the equipment decrease significantly. Or the line speed can be increased and hence decrease the specific cleaning cost.
5. I have proved that the lower temperature larger pressure combination is more advantageous energetically than the higher temperature-lower pressure combination if the temperature and pressure operation parameter pairs reaching the same cleaning effect.
6. It has to be paid attention on the setting the proper values of the operation time and the cleaning agent concentration among the operation parameters of the optimal cleaning technology first of all. On the base of my investigation I propose, that choose the shorter operation time and higher cleaning agent concentration from among the above mentioned parameter pairs reaching the maximal cleaning efficiency. The effect of the operation time on the specific cost is three times higher than the cleaning agent concentration.
7. The choosing of the cleaning agent removing the contamination type in the highest efficiency is the prime task because it makes up about 60% of the total expenditures.
   According to the cost analysis of the cleaning, considering the line speed/operation time as constant, the operation parameters have the following affect on the cost of cleaning in descending order:
   - Type and concentration of the cleaning agent
   - The temperature of the cleaning solution
   - Pressure of the cleaning solution on the washing frame.
8. The technology and the equipment proposed on the base of my investigation are suitable for the multi task use. The effective cleaning technology can be set by the controllable parameters according to the contamination type and measure. The moving of the crates on the sides and the adjustable line construction provide the cleaning of the crates/boxes in different size in case of the combined ultrasonic technology.
9. The method for the determination of the measure of the cleaning, developed by me, is suitable for determining the expectable level of cleaning efficiency and for comparison and qualification of different cleaning agents.

6. PUBLICATION IN THE THEME OF DISSERTATION

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