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Study of using automatic milking systems on large dairy farms

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ABSTRACT: To explain particularly the economical aspects of AMS application in large-scale stables in comparison with the parlour milking there were designed two almost identical free box stables with four rows of boxes for 300 dairy cows each. The first one is equipped with two AMS Leonardo with four milking stalls and one preparatory box. The comparative stable is equiped with the herringbone parlour with 2 × 12 milking stalls; rapid exit, automated identification and automated data collection are used for milking. The costs of stable with milking in milking parlour including milking parlour and milk store room are by 7% higher than similar costs for stable with milking in AMS. In contrast to this the costs for technical equipment of stable are by 185% higher in stable with milking in AMS than those in stable with milking parlour. The highest share of the increased costs is due to the AMS price, which is by 361% higher than the milking parlour price. Total investment costs of stable for 300 dairy cows with milking in AMS are by 17.35 mil. CZK (i.e. by 62.6%) higher than those of stable with milking parlour. These costs are then shown in total operational costs of stable and costs per production of 1 litre of milk so that total annual costs on farm for 300 dairy cows with milking in AMS are under similar conditions by 9.9% higher in comparison with identical farm but with milking in milking parlour. In comparison of the both milking systems it is necessary to take into account, that at 3-time daily frequency of milking there was reached the same effect of milk yield increase as at voluntary milking in AMS. A certain problem seems to be the deterioration of reproduction parameters in consequence of increased milking frequency. Due to change into 3-time daily milking the conception has deteriorated (insemination index has increased by 0.4), the interval has extended by 18.1 days and service period has increased by 6.3 days.

Keywords: robotic milking; parlour milking; production costs

On modern dairy farms in the CR normally 200–800 cows are kept. This size of farms is not suitable for current AMS utilisation and it is connected with problems, which have to be analysed in details. It concerns particularly the constructional and disposal solution of current stables with respect to the AMS requirements and to a realistic possibility of their reconstruction, the AMS effectiveness in connection with the total number of milked cows in one stable and on the farm, the milk yield of raised dairy cows and the possible contributions resulting from transformation to AMS milking, AMS contributions to social and working conditions on Czech dairy farms as well as the economical aspects of AMS application as compared with parlour milking.

In the 90s the basic development of AMS (Automatic Milking System) was finished and now it is rapidly extending within European farms for dairy cows keeping. It concerns mainly the farms with a relatively low number of dairy cows (40–150 cows). Dairy farms in Czech Republic are generally larger. This farm size inflicts considerable problems when using current AMS. These problems have to be analysed in details (VEGRICHT 1999). It regards particularly:

- Constructional and disposal design of current stables in relation to the AMS demands and realistic possibilities of their reconstruction.
- AMS performance with respect to total number of dairy cows in one stable and on farm.
- Dairy cows milk yield and possible benefits resulting from change to AMS milking.
- AMS benefits in social sphere on dairy farms in CR.
- Economical aspects of AMS utilisation in comparison with milking in milking parlour.

The real performance of current AMS is for single-box system max. 60 dairy cows and for multi-box system max. 150 dairy cows per day (SCHÖN 2000). In larger stables and on large – size farms it calls for installation of some AMS to reach total output corresponding with number of housed dairy cows. With respect to requirements on free movement of the cows to AMS, to feeding place and to box bed it seems that the most simple and the cheapest solution for application of this milking system will be the construction of new, light stable providing AMS requirements for size and constructional and disposition solution (VEGRICHT 2000).

This contribution is based on results of the National Agency for Agricultural Research project solution with financial support of the Ministry of Agriculture of the CR, No. QD 0176 and of the research goal MEZM 05-9901.

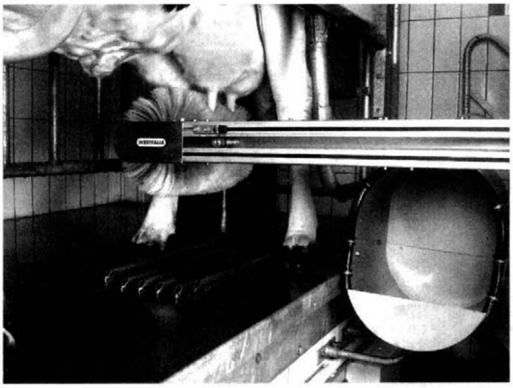


Fig. 1. AMS Leonardo-preparing box with brush teat cleaner

The average milk yield of dairy cows in CR in 2000 has reached about 5,300 l. Considering the lowest limit of milk yield for AMS application 8,000 l/year which is a condition for achievement of milk yield increase in consequence of multiple milking, this system application may be a case over for about 10% of dairy cows in CR. The similar effect can be reached for parlour milking as found out e.g. during experiments carried – out by DOLEŽAL et al. (1999), who found the milk yield increase by about 18.9% when milking process has changed to 3 times daily. The contributions obtained by milk yield increase have to balance the wages, energy and feedstuffs cost increase, deteriorated reproduction indicators, increased wear of milking apparatus, disinfections etc. A certain problem seems to be the deterioration of reproduction parameters in consequence of increased milking frequency. Due to change into 3 times daily milking the conception has deteriorated (insemination index has increased by 0.4), the interval has extended by 18.1 days and the service period has increased by 6.3 days (DOLEŽAL et al. 1999).

The social benefit of the AMS milking application is not so expressive under conditions of larger farms with shift work character as compared with family "single – man" farms. Higher amount of workers on farm enables to maintain adequate working time and change of workers enabling them to have a free time in regular intervals. Just this aspect of AMS application (elimination of energy day presence of farmer at morning and evening hours in stable during milking) is in many cases decisive for AMS purchase on small dairy farms. The milk production economy is on the Czech farms the most important criterion for all investment decisions. The conditions of the Czech farmers are at present considerably different from the situation of farmers in the EU countries. For example, when the single-box AMS price will be expressed by amount of milk which the Czech farmer has to sell as compared with e.g. the German farmer,

Table 1. Effect of milk yield change during standardised lactation (DOLEŽAL 1999)

Group	Number of finished lactions	Unit	Milking frequency in one day		Change
			2×	3×	(%)
A	148	kg	5,422 ± 720	5,498 ± 595	1.4
B	102	kg	6,228 ± 782	6,776 ± 801	8.8
C	48	kg	7,122 ± 788	8,468 ± 922	18.9

Table 2. Investment costs per stable for 300 dairy cows with milking in herringbone parlour 2 × 12 with rapid exit, 10^3 CZK

Item	Description	Investment costs
Stable construction	6-row stable with central feeding corridor and number of feeding places at trough 1:1.5, ground plan 32 × 72 m	9,216
Milking parlour with milk store room	Herringbone milking parlour with 2 × 12 milking stalls and waiting room (1.5 m^2/cow)	4,976
Slurry and waste water reservoir	Storage capacity 6 months, 3,500 m^3	3,500
Construction costs in total		17,692
Internal equipment of stable	Fence, drinking, mattress	1,800
Manure removal	2 × 2 scrapers	1,000
Milking parlour	Herringbone 2 × 12 with rapid exit, milk flow – meters, pedometer, PC, fence, el. driver	4,910
Milk cooling and storage	2 cooling tanks, 2 × 6,500 l, recuperation	1,200
Feeding	Feeding wagon with auger, 12 m^3	1,100
Total technology costs		10,010
Total investment costs		27,702
Total investment costs calculated to 1 housing stall		92.34

Table 3. Investment costs of stable for 300 dairy cows with milking in 2× AMS Leonardo, 10^3 CZK

Item	Description	Investment costs
Stable construction	4-row stable with 2× AMS Leonardo, feeding stall situated laterally, ratio of feeding places at through 1:2, ground plan 22 × 124.8 m	11,704
Milk store room	Storage capacity 13,000 l	1,326
Slurry and waste water reservoir	Storage capacity 6 months, 3,500 m³	3,500
Construction costs in total		16,530
Internal equipment of stable	Fence, drinking, mattress	1,800
Manure removal	2 × 2 + 2 scrapers	1,800
Milking	2× AMS Leonardo, each 4 + 1 box, pedometers	22,620
Milk cooling and storage	2 cooling tanks with recuperation, 2 × 6,500 l	1,200
Feeding	Mixing feeding wagon with auger, 12 m³	1,100
Total technology costs		28,520
Total investment costs		45,050
Total investment costs over – calculated to 1 housing stall		150.17

than at this AMS price 300,000 DEM and milk realisation price 0.60 DEM/l and 7.50 CZK/l and currency rate 18.50 CZK/DEM the German farmer has to sell 500,000 litre of milk, but Czech farmer 740,000 litre, i.e. by 48% more.

METHODICAL PROCESS

For purposes how to determine economical aspects of AMS utilisation for milking on large farms corresponding with needs and requirements of the Czech Republic there were compared in model two stables for 300 dairy cows of which one was equipped for milking by herringbone parlour 2 × 12 with rapid exit and automated data collection and the second stable equipped by two AMS Leonardo, of which each has 4 milking stalls and 1 preparation box (Figs. 1 and 2).

The ground plan scheme of these stables is shown in Figs. 3 and 4. In this connection is necessary to emphasise the model character of these stables design, where e.g. stable with AMS is extremely long. Therefore before eventual implementation it would be suitable to solve many details and to cooperate with the AMS manufacturer. For this study purposes this design is quite sufficient.

For these stables were determined in model the necessary investment costs and computed costs per 1 litre of milk production. The calculation was based on the basic milk yield of 9,000 litres per 1 cow and year. In consequence of the increased milking frequency using AMS it is presumed to increase milk yield by 15% to 10,350 l per cow and year. Because according to experiences the same effect can be reached at milking 3 times daily in milking parlour, the calculation was completed also this case, i.e. milk yield increase to 10,350 l at 3 times daily milking on farm with herringbone milking parlour 2 × 12.

In the calculation was involved as well the saving of one milker for AMS milking in comparison with parlour

Table 4. Total annual costs per milk production in milking parlour and AMS Leonardo, 10^3 CZK

Item	Stable for 300 dairy cows with milking parlour	Stable for 300 dairy cows with AMS
Personal costs	1,276	1,087
Feedstuffs	10,950	10,950
Dairy cows depreciation	3,285	3,285
Technology depreciation	1,368	4,453
Construction depreciation	650	611
Breeding and vet services	1,424	1,643
Other costs	1,752	2,081
Overhead	1,314	1,314
Total costs	22,019	24,187
Costs per production of 1 litre of milk at milk yield 9,000 l (CZK)	8.49	9.33
Costs per production of 1 litre of milk at milk yield 10,350 l (CZK)	7.39	8.12

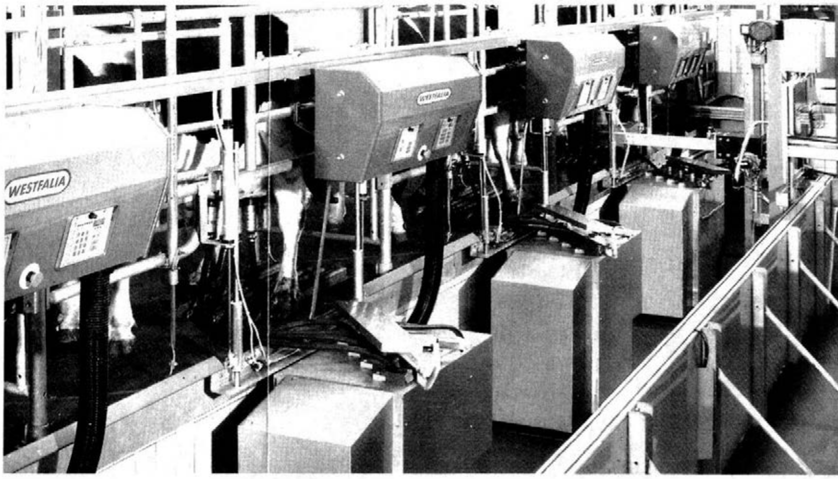


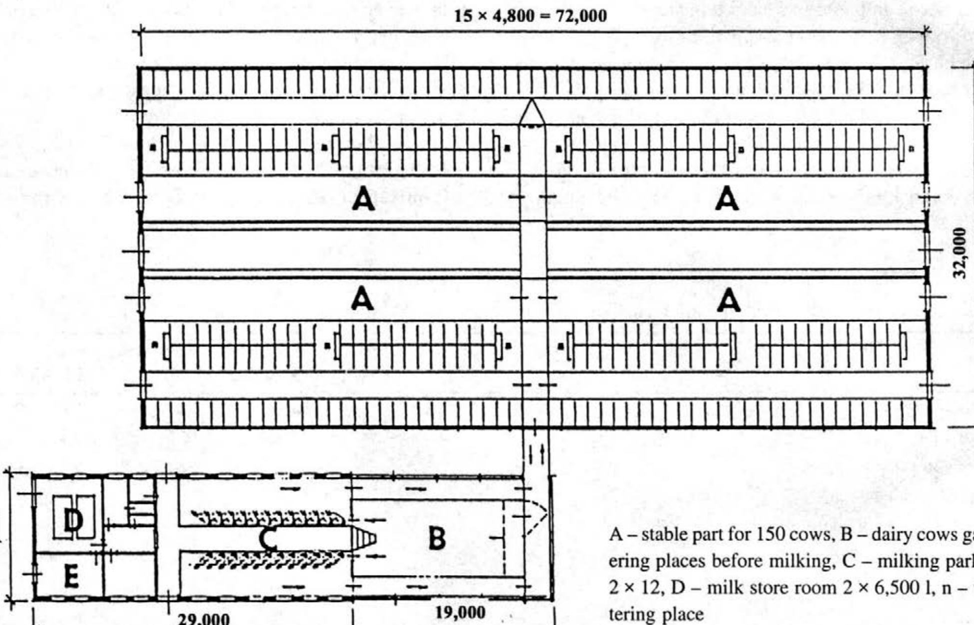
Fig. 2. AMS Leonardo-over view on milking boxes

milking, because recent experiences show that even the milking system in AMS needs certain man activity.

RESULTS AND DISCUSSION

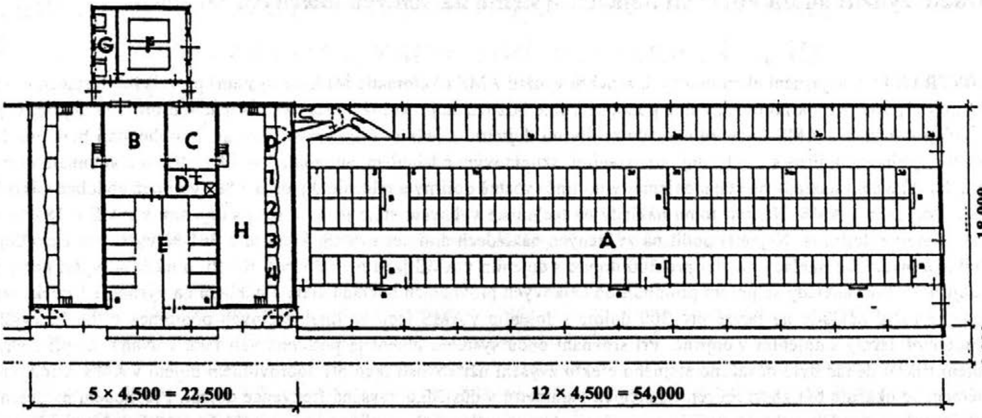
In Table 2 are presented investment costs and their structure for a stable for 300 dairy cows with parlour milking (Fig. 1) and in Table 3 are presented similar costs for stable with milking in AMS (Fig. 2).

The construction costs per stable with parlour milking including parlour and milk store room are by 7% higher than those per milking in AMS. This can be explained by the milk store room being situated in stable and by absence of dairy cows gathering place before milking in stable with milking in AMS. In contrast with this, the costs per stable technical equipment are for stable with milking in AMS by 185% higher than for the stable with milking parlour. The highest share of increased costs is



A – stable part for 150 cows, B – dairy cows gathering places before milking, C – milking parlour 2 × 12, D – milk store room 2 × 6,500 l, n – watering place

Fig. 3. Stable for 300 dairy cows and herringbone parlour 2 × 12 with rapid exit



A – stable part for 150 cows, B – machine room, C – office room, D – washing room, WC, E – pens for trouble cows, F – milk store room 2 × 6,500 l, G – cooling aggregates, H – AMS Leonardo, P – preparation box, n – watering place

Fig. 4. Stable for 300 dairy cows and milking in 2 × AMS Leonardo 4 + 1 boxes

due to the AMS price, which is by 361% higher that the milking parlour price. Total investment costs per stable for 300 dairy cows with milking in AMS are by 17.35 mil. CZK (i.e. by 62.6%) higher than, those for the stable with milking parlour.

These costs will appear in total operational costs of the stable and production of 1 litre of milk presented in Table 4. Total annual costs on farm for 300 dairy cows with milking in AMS are under almost identical conditions by 9.9% higher as compared with a similar farm with parlour milking. A comparison of both systems needs to take into account that the 3 times daily frequency of milking allowed to reach the same effect of milk yield increase as in voluntary milking in AMS.

A certain problem seems to be the reproduction parameters deterioration in consequence of increased milking frequency. During tests in the Research Institute of Animal Production in Prague (DOLEŽAL 1999) the conception has deteriorated with change to the 3 times daily milking (insemination index has increased by 0.4), the interval has extended by 18.1 days and service period has increased by 6.3 days. Explanation of these problems will need a priority attention.

In connection with the AMS also development of partial milking devices was significantly sophisticated, particularly the automated monitoring of mammary gland health status and milk quality. This has a positive effect on the technical level improvement of other milking devices.

For stables with higher number of animals it will be purposeful to focus the next development to multi-box systems of AMS with arrangement of milking stalls, e.g. within the circle perimeter enabling to reach better animals passage.

It also would be useful to reduce the time for AMS milking apparatus application as one of the presumptions to increase their performance and better utilisation of the robotised arm what will bring relative price cut down of one milking process.

On the large-size farms the positive contributions can be considered in the replacement of tiresome milker work and the introduction of standard milking quality and high milk quality independent of the human factor.

The basic condition for AMS application will be economy, i.e. AMS effect on the milk production costs and its realisation price. It considers mainly the high purchase price of AMS, which is so far the invincible obstacle for the Czech farmer. Therefore in near future we do not expect application of this milking method in conditions of Czech farms.

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Studie využití automatických dojicích systémů na velkých mléčných farmách

ABSTRAKT: K vyjasnění ekonomických aspektů využití AMS (Automatic Milking System) na velkých farmách pro chov dojnic byly navrženy a porovnány dvě podobné volné boxové stáje, každá s ustájovací kapacitou pro 300 dojnic. U první zajišťují dojení dva AMS Leonardo, každý se čtyřmi dojicími a jedním přípravným boxem. V druhé stáji byla pro dojení použita rybinová dojírna s 2 × 12 dojicími stáními, skupinovým odchodem, automatickou identifikací a automatickým sběrem dat. Stavební náklady na stáj s dojením v dojírně (včetně dojírny a mléčnice) jsou o 7 % vyšší než obdobné náklady na stáje s dojením v AMS. Naproti tomu náklady na technické vybavení stáje jsou ve stáji s dojením v AMS o 185 % vyšší než ve stáji s dojírnou. Největší podíl na zvýšených nákladech činí cena AMS, která je o 361 % vyšší než cena dojírny. Celkové investiční náklady na stáj pro 300 dojnic s dojením v AMS jsou o 17,35 mil. Kč (tj. o 62,6 %) vyšší než u stáje s dojírnou. Tyto náklady se potom promítají do celkových provozních nákladů stáje a nákladů na výrobu 1 l mléka tak, že celkové roční náklady na farmě pro 300 dojnic s dojením v AMS jsou za jinak stejných podmínek o 9,9 % vyšší než u podobné farmy s dojením v dojírně. Při srovnání obou systémů dojení je potřebné vzít také v úvahu, že při frekvenci dojení třikrát denně bylo dosaženo stejného efektu zvýšení užitkovosti jako při dobrovolném dojení v AMS. Určitým problémem se ukazuje být zhoršení reprodukčních parametrů v důsledku zvýšené frekvence dojení. Přechodem na dojení třikrát denně se zhoršilo zabřezávání (inseminační index vzrostl o 0,4), prodloužilo se mezidobí o 18,1 dnů a servis perioda vzrostla o 6,3 dnů.

Klíčová slova: AMS; dojírna; mléko; výrobní náklady

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Regulation of vacuum in milking machines by unit with pressure reducing valve and assessment of its basic parameters

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ABSTRACT: The author designed a unit with the pressure reducing valve to control vacuum at the simultaneous control of vacuum pump operation. No additional atmospheric air is needed to be sucked in for vacuum control. The vacuum pump is passed through only by air consumed by the milking machine, i.e. a considerably lesser amount than with the classical control valve. The use of special control unit with the pressure reducing valve makes it possible to reduce the consumption of electric energy. The paper discusses the issue of choosing optimum parameters of the unit on the basis of a theoretical analysis with the subsequent experimental verification.

Keywords: milking machines; vacuum control; reduction of energy consumption

Research and development in the field of milking technology is usually focused on internal links of the biotechnical system *man – dairy cow organism – milking machine – environment.* There has been a lot of success in this field, which can be documented by the existence of functional milking robots and by the fact that the process of machine milking itself gets accommodated to the individuality of the dairy cow. A considerably less attention was so far paid to energy demands of milking machines. And it is exactly these problems that recently appear in the limelight, particularly in connexion with ecological and economic aspects. Electric energy consumed in vain does not represent only increased costs for the operator, but also an unnecessary environmental load relating to the generation of electric energy. One of the weakest points from the viewpoint of energy utilization is the method of vacuum control.

MATERIAL AND METHOD

In the classical method of vacuum magnitude regulation the vacuum pump is passed through by far a greater air volume than required for the operation of milking machine (PŘIKRYL 1997). The method of vacuum control by pressure reducing valves issues from the pump characteristic at constant speed. It follows that should we wish to achieve a constant vacuum, the pump must be passed through by a constant air volume (LOWE 1981). Regarding the fact that the air volume sucked in by the milking machine is variable in time, the pressure reducing valve has to add such a volume of atmospheric air into the vacuum system that would make the sum of air volume sucked in by the milking machine and pressure reducing valve per unit time constant. It further follows that the vacuum pump goes on working at full performance with no regard to the actual consumption of air by the milking machine (PŘIKRYL et al. 1994).

This is the reason why there has designed a unit for vacuum control, in which no atmospheric air would be additionally sucked in. The vacuum pump is passed through only by air from the milking machine, and its operation is controlled in dependence on the instantaneous consumption of air. The unit principle is illustrated in the diagram (Fig. 1). The vacuum pump set is connected directly to the large-volume air-chamber (big

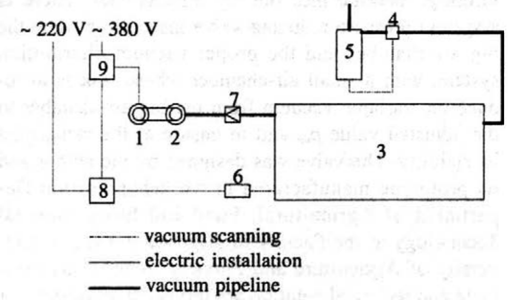

Fig. 1. Functional diagram of unit with pressure reducing valve. 1 – electric motor; 2 – vacuum pump; 3 – big air chamber; 4 – pressure reducing valve; 5 – small air chamber; 6 – vacuum probe; 7 – back-pressure valve; 8 – electronic control unit; 9 – contactor

The paper has come into existence within the framework of the Grant MSM No. 432100001.

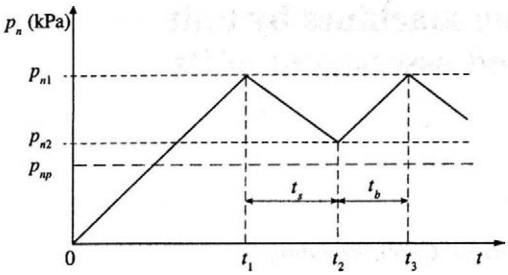

Fig. 2. Vacuum control in big air-chamber by electronic unit p_{n1} – switch-off vacuum; p_{n2} – switch-on vacuum; p_{np} – working vacuum in milking machine

air-chamber). The connection tubing between the pump and the big air-chamber is provided with a back-pressure valve to prevent reversed motion of the pump when the electric motor is switched-off and thus undesirable suction of air occurring due to the action of vacuum from the big air-chamber. The big air-chamber vacuum is maintained by the pump within a selected range p_{n1} to p_{n2} ($p_{n1} > p_{n2}$) so that the minimum value (p_{n2}) is higher than the working vacuum in the milking machine (p_{np}) – Fig. 2.

This function is then provided by the vacuum transducer which scans the instantaneous value of vacuum in the big air-chamber and controls the contactor of vacuum pump electric motor via the electronic control member. The contactor would switch-on when vacuum falls to the minimum value (p_{n2}) and switch-off after the maximum adjusted value (p_{n1}) has been reached. This means that the pump operation is not continual; there are alternating time intervals when the pump is in/off the operation. These time intervals depend on pump efficiency, volume of big air-chamber, range of pressures between the contactor switching ons and offs, and on the instantaneous air flow sucked from the milking machine into the big air-chamber. There is a special pressure reducing valve inserted between the big air-chamber and the proper vacuum distribution system, with a small air-chamber whose task is to reduce the variable vacuum from the big air-chamber to the adjusted value p_{np} and to ensure at the same time its stability. The valve was designed by the author and its prototype manufactured in workshops of the Department of Agricultural, Food and Environmental Technology at the Faculty of Agronomy, Mendel University of Agriculture and Forestry in Brno; its principle and technical solution are protected by patent.

Basic pre-condition for the unit to function is that the on/off switching does not occur in extremely short intervals. Variable decisive for these intervals is the volume of big air-chamber. Other construction parameters influencing the intervals include the vacuum pump efficiency and the magnitude of on/off switching vacuums. Volume of air V_{ar} sucked into the air-chamber of the volume V_w when the vacuum drops from the p_{n1} value to the value p_{n2} – measured at atmospheric air pressure – can be expressed as a difference of air volumes in the air-chamber at the vacuums p_{n1} and p_{n2} converted to atmospheric air pressure.

$$V_{ar} = V_{a2} - V_{a1} \quad (\mathrm{m}^3) \tag{1}$$

where: V_{a1} – air-chamber volume of air at the vacuum p_{n1} converted to atmospheric pressure (m³),
V_{a2} – air-chamber volume of air at the vacuum p_{n2} converted to atmospheric pressure (m³).

According to the Boyle-Mariott law, relations hold as follows:

$$V_w \cdot (p_a - p_{n1}) = V_{a1} \cdot p_a \tag{2}$$

$$V_w \cdot (p_a - p_{n2}) = V_{a2} \cdot p_a \tag{3}$$

where: p_a – atmospheric pressure (whose ISO 6690 value for elevation 0–300 m is 100 kPa).

After substitution into the relation (1) and its adjustment we arrive at a resulting relation as follows:

$$V_{ar} = V_W \frac{p_{n1} - p_{n2}}{p_a} \quad (\mathrm{m}^3) \tag{4}$$

Regarding the fact that the vacuum pump operates within the vacuum range from p_{n2} to p_{n1}, its efficiency changes in a linear way in dependence on vacuum. It is therefore necessary to determine at least the mean value of vacuum pump efficiency for further theoretical analysis.

There is a general relation holding for vacuum pump efficiency:

$$Q_{vn} = Q_{v0} \frac{p_a - p_n}{p_a} \quad (\mathrm{m}^3/\mathrm{s}) \tag{5}$$

where: Q_{vn} – pump efficiency at the vacuum p_n (m³/s),
Q_{v0} – pump efficiency at zero vacuum (m³/s).

By adjusting the above relation the vacuum pump efficiency at the change of vacuum from p_n to p_{nx} can be expressed by the following term:

$$Q_{vx} = Q_{vn} \frac{p_a - p_{nx}}{p_a - p_n} \quad (\mathrm{m}^3/\mathrm{s}) \tag{6}$$

where: Q_{vn} – pump efficiency at the vacuum p_n (m³/s),
Q_{vx} – pump efficiency at the vacuum p_{nx} (m³/s).

Time regime of vacuum pump electric motor switch ons and offs depends on the big air-chamber volume V_w or on the volume V_{ar}, vacuum pump efficiency Q_{vx} corresponding to the vacuum, and on the consumption of air Q_s by the milking machine. The time interval of pump operation can therefore be expressed by the following relation:

$$t_b = \frac{V_{ar}}{Q_{vx} - Q_s} \quad (\mathrm{s}) \tag{7}$$

The time interval when the vacuum pump does not work is given by the following relation:

$$t_s = \frac{V_{ar}}{Q_s} \quad \text{(s)} \tag{8}$$

If the value Q_s approaches zero, then the values t_b acquire minimum and t_s approaches + ∞ which indicates that the vacuum pump is permanently switched off. On the other hand, if the value Q_s approaches the value Q_{vx}, then the values t_s acquire minimum and t_b approaches + ∞, which indicates that the vacuum pump is permanently in operation. The vacuum pump working range should be between the boundaries. The condition for the operation of control unit can therefore be expressed as follows:

$$0 < Q_s < Q_{vx} \tag{9}$$

Optimum for vacuum pump operation can be considered to be the centre of the range, i.e. when the values t_b and t_s are equal. To define the optimum we can therefore write:

$$t_b = t_s \tag{10}$$

By substituting from the relations (7) and (8) we arrive at a following equation:

$$\frac{V_{ar}}{Q_{vx} - Q_s} = \frac{V_{ar}}{Q_s} \tag{11}$$

Solving the equation we obtain a relation for the required vacuum pump efficiency as follows:

$$Q_{vx} = 2\,Q_s \quad (\mathrm{m^3/s}) \tag{12}$$

It follows from the relation (12) that the vacuum pump efficiency Q_{vx} at the mean value of working vacuum should be the double average value of actual air consumption.

From the viewpoint of unit operation the intervals of switch-ons/offs should be preferrably as long as possible; on the other hand, an air-chamber with the volume of several cubic meters is rather costly. Another pre-condition is that the switch-ons/offs are not too frequent which could result in the vacuum pump system damage. We have to bear in mind that on the condition of one interval approaching its minimum, the other one will be approaching its maximum. Taken from this point of view, it is recommended to rather see to the length of time interval in one switching cycle t_c for which a relation holds that:

$$t_c = t_b + t_s \quad \text{(s)} \tag{13}$$

For this length of time, the vacuum pump electric motor contactor switches on and off once. A limiting variable for the design of control unit parameters is a minimum of this function, which occurs if $t_b = t_s$.

RESULTS

Vacuum pump employed in the experiments was Model DVL 220 of specific efficiency 7.5 dm³/s (450 l/min) at the vacuum of 50 kPa; this value was used for further calculations.

Dependence of the volume V_{ar} according to the relation (4) for the chosen volumes of big air-chamber V_w = 1 m³, 2 m³ and 4 m³ and difference of vacuums p_{n1}–p_{n2} in the range from 0 to 15 kPa for the value of atmospheric pressure p_a = 100 kPa are illustrated in Fig. 3. It follows from Fig. 3 that both the increasing size of big air-chamber and the increasing pressure difference p_{n1}–p_{n2} result in the growing volume V_{ar}. The choice of these variables is then given by other limiting values.

For a correct function of pressure reducing valve it is necessary to observe a minimum difference between the working vacuum and the lower vacuum boundary in the big air-chamber, which should be about 3–5 kPa.The difference between the vacuum minimum and maximum in the big air-chamber is assumed to be – with regard to the intervals of vacuum pump electric motor switching on/off – 5 to 10 kPa. Should we consider the lowest values and should the working pressure be 50 kPa, then the mean vacuum in the big air-chamber is going to be 55.5 kPa. If we – on the other hand – consider the maximum values, the mean vacuum in the big air-

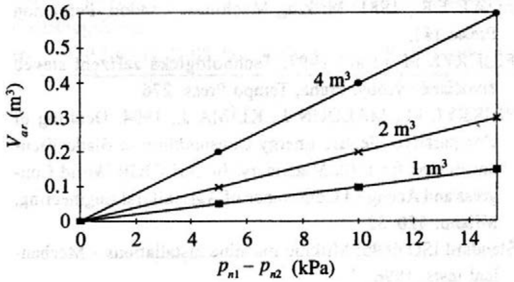

Fig. 3. Dependence of air volume sucked into big air-chamber on the magnitude of vacuum change and on the volume of big air-chamber

V_{ar} – air volume (m³), $p_{n1} - p_{n2}$ – pressure difference (kPa)

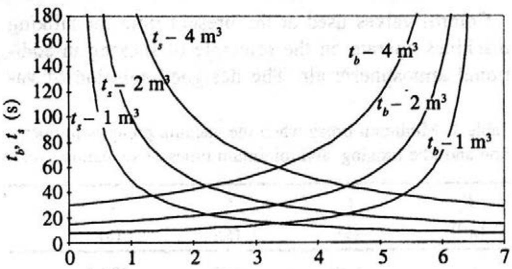

Fig. 4. Dependence of vacuum pump operation and idle time on air consumption and on big air-chamber volume

t_b, t_s – time intervals (s) Q_s – air consumption (dm³/s) chamber will be 60.0 kPa. If we substitute the values into the relation (6), we obtain the mean value of vacuum pump efficiency. For the vacuum pump Model DVL 220 this will be 6.7 dm^3/s (400 l/min) at p_{nx} = 55.5 kPa, and 6.0 dm^3/s (360 l/min) at p_{nx} = 60.0 kPa. We can see from the calculations that in the first case the mean value of vacuum pump efficiency dropped by 11% and in the second case it decreased by 20% which is a too high value regarding the fact that the vacuum pump input power is increasing as well. Therefore, a difference between the working vacuum and the lower vacuum boundary in the big air-chamber was designed to be 3 kPa, and the difference between the vacuum minimum and maximum in the big air-chamber was designed to be 5 kPa.

Theoretical values of time t_b and time t_s were calculated for the designed pressure conditions and for the volumes of big air-chamber 1, 2 and 4 m^3 according to the relations (7) and (8) in dependence on the consumption of air by the milking machine. The dependences are illustrated in Fig. 4. In order to assess the regime of vacuum pump swiching on and off, the minimum values of time intervals t_b and t_s must be determined together with the minimum value of switching cycle t_c. For the calculation of the minimum time intervals t_b and t_s let us consider the values Q_s = 0 and Q_s = Q_{vx} to be limiting values and let us substitute them into the relations (7) and (8). For the calculation of the minimum switching cycle t_c the relations (7), (8) and (12) are to be substituted into the equation (13). Results are in Table 1.

The time of one switching cycle for the big air-chamber with the volume of 1 m^3 will not fall below 30 sec and the minimum values of t_b and t_s are 7.5 s. The parameters can be considered sufficient at least for the laboratory measurement.

The theoretically calculated values were verified by experimental measurements. All values were adjusted to the theoretical design with only the used air-chamber being of 1.2 m^3 in volume. The theoretical and actually measured values are presented in Table 2.

DISCUSSION

Control valves used at the present time for milking machines operate on the principle of sucking in additional atmospheric air. The designed solution of vacuum control in milking machines gives a good pre-condition for savings of electric energy since the vacuum pump is passed through only by the air which is consumed by the milking machine and the vacuum pump operation is controlled to the actual consumption of air. On the other hand, it is neccesary to consider the fact that the vacuum pump works with the higher vacuum, which results in its lower efficiency and higher input power. In general, the vacuum pump efficiency will be impaired and therefore it is necessary to design the regime of operation on the basis of the issue analysis in such a way that the expected effect is achieved. The above measurements corroborated the theoretical hypotheses with a certain deterioration of parameters having resulted from leakages and particularly from a large connection volume between the pump and the back-pressure valve. The unit parameters are expected to improve after the introduction of regulation by frequency converter, which is in preparation. The vacuum pump will not be switching on and off but its rotations are going to be continually altered.

Table 1. Minimum times when the vacuum pump is in operation and idle running, and minimum times of switching cycle

V_w (m^3)	t_b (s)	t_s (s)	t_c (s)
1	7.49	7.49	29.96
2	14.98	14.98	59.92
4	29.96	29.96	119.84

Table 2. The theoretical and actually measured values of minimum times when the vacuum pump is in operation and idle running, and minimum times of switching cycle

V_w (m^3) 1.2	t_b (s) minimum	t_s (s) minimum	t_c (s) minimum
Theoretical	8.99	8.99	36.96
Measured	7.8	5.1	24.2

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Regulace podtlaku dojicích strojů zařízením s redukčním ventilem a určení jeho základních parametrů

ABSTRAKT: Bylo navrženo zařízení pro regulaci podtlaku, u něhož se nepřisává žádný atmosférický vzduch. Vývěvou prochází pouze vzduch z dojicího stroje a v závislosti na okamžité spotřebě vzduchu se řídí chod vývěvy. Princip zařízení je znázorněn na obr. 1. Soustrojí vývěvy je připojeno přímo na vzdušník o velkém objemu (v textu je označován termínem „velký vzdušník"). Ve velkém vzdušníku je vývěvou udržován podtlak ve zvoleném rozmezí p_{n1} až p_{n2} ($p_{n1} > p_{n2}$) tak, aby minimální hodnota (p_{n2}) byla vyšší než pracovní podtlak v dojicím stroji (p_{np}) (obr. 2). Při poklesu podtlaku na minimální hodnotu (p_{n2}) dojde k sepnutí stykače a po dosažení nastavené maximální hodnoty (p_{n1}) dojde k jeho rozepnutí. Vývěva tedy nepracuje trvale, ale střídají se časové intervaly, kdy vývěva pracuje a kdy není v činnosti. Mezi velkým vzdušníkem a vlastním rozvodem podtlaku je vřazen speciální redukční ventil s malým vzdušníkem, který snižuje proměnný podtlak z velkého vzdušníku na nastavenou hodnotu p_{np} a zároveň zabezpečuje jeho stabilitu. Princip a technické řešení zařízení je patentově chráněno. Z hlediska činnosti zařízení je žádoucí, aby intervaly zapínání a vypínání byly co nejdelší. Veličina, která rozhodujícím způsobem určuje tyto intervaly, je objem velkého vzdušníku. Dalšími konstrukčními parametry ovlivňujícími tyto intervaly jsou výkonnost vývěvy a velikost spínacího a vypínacího podtlaku. Je podstatné, aby frekvence spínání a vypínání nebyla tak častá, že by to mohlo vést k poškození soustrojí vývěvy. Za stavu, kdy se jeden z intervalů blíží svému minimu, druhý nabývá maxima. Z tohoto hlediska je vhodné sledovat raději délku časového intervalu jednoho spínacího cyklu t_c. Za tuto dobu stykač elektromotoru vývěvy jednou sepne a jednou vypne. Limitující veličinou pro návrh parametrů zařízení je minimum této funkce. Pro navržené tlakové poměry a pro objemy velkého vzdušníku 1, 2 a 4 m^3 byly podle vztahů (7) a (8) vypočteny teoretické hodnoty doby t_b a doby t_s v závislosti na spotřebě vzduchu dojicím strojem. Tyto závislosti jsou vyjádřeny na obr. 4. Pro posouzení režimu spínání a vypínání vývěvy je třeba určit minimální hodnoty časových intervalů t_b a t_s a minimální hodnotu spínacího cyklu t_c. Získané hodnoty obsahuje tab. 1. Doba jednoho spínacího cyklu pro velký vzdušník o objemu 1 m^3 neklesne pod 30 s a minimální hodnoty t_b a t_s jsou 7,5 s. Tyto parametry lze považovat alespoň pro laboratorní měření za dostačující. Teoreticky vypočítané hodnoty byly ověřeny experimentálním měřením. Všechny hodnoty byly nastaveny podle teoretického návrhu, pouze použitý vzdušník měl objem 1,2 m^3. Teoretické a skutečně naměřené hodnoty jsou uvedeny v tab. 2. Navržené řešení regulace podtlaku dojicích strojů dává předpoklad úspory elektrické energie, protože vývěvou prochází pouze vzduch spotřebovávaný dojicím strojem a chod vývěvy je řízen podle skutečné spotřeby vzduchu, i když vývěva pracuje s vyšším podtlakem, což má za následek její nižší účinnost.

Klíčová slova: dojicí stroje; regulace podtlaku; snížení spotřeby energie

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Influence of detergents and disinfectants on the physical and mechanical properties of liners

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ABSTRACT: The hardness of synthetic rubbers is increasing in the course of exploitation due to the effects of cleaning and disinfection agents, milk and mechanical stress, and the increased liner hardness results in teat traumatization during milking. Obtained results were processed for hardness, strength and extensibility analyses as depending on usage hours of liners and milk tubes in milking. In other combinations of liners and cleaning/disinfection systems the hardness of liners decreases with the increasing time of their usage. In contrast, the strength of liners would be increasing in all cases of combinations of liners and cleaning/disinfection systems. The values of liners strength were neither affected by any of the studied factors (liner type, cleaning agent, usage time) nor by their interactions. The lowest strength values were reached in the combination of SN1 and cleaning agent B (12.89 MPa).

Keywords: liner; rubber ageing; physical and mechanical properties of rubbers; detergents and disinfectants

A crucial hygienic measure in primary milk production is the elimination of microbiological contamination. Here, the decisive factor is a good condition of all working surfaces of the milking installation, which come into contact with milk during milking and could cause secondary milk contamination. The most stringent requirements are therefore imposed on the quality of liners, which as the only ones come into the contact with the living organism (teats) and with milk. Mechanical properties of rubber and the quality of liner internal-working surface deteriorate during the action of the working environment (milk, animal fats, disinfection and cleansing means, mechanical stress at pulsation, etc.). The liners are exposed to the process of very complicated mechanical, physical, chemical and biological wearing.

Similar requirements as those put onto the liners should be met by milk tubes. The Standard ČSN 46 6109 *Cleaning and disinfection in primary production of milk and its dairy treatment and processing* has been in force since 1 July 1977.

Microbiological requirements for milk and milk products are at the present time defined in the Czech Republic by the following documents (Kadlec 2000): Decree of the CR Ministry of Agriculture No. 287/99 Gaz. on veterinary requirements for animal products; Decree of the CR Ministry of Health No. 249/97 Gaz. on microbiological requirements for foodstuffs, methods of their control and assessment in the version of Decr. No. 91/99 Gaz.; ČSN 57 0529 *Raw milk for dairy treatment and processing.*

The whole issue is further treated by other norms for milk products, which follow up to the above decrees.

Undesirable microorganisms in milk as considered by Kadlec (2000) are the following ones: pathogenic microorganisms (originators of ailment); originators of anthropozoonoses (animal→man); toxins generating microorganisms; saprophytic microorganisms (originators of food deterioration, lipolyses and proteolyses in particular).

In working conditions it is particularly the working surface of liners and milk tubes, which is degraded first (Gálik, Kováč 2000). There is no appropriate testing facility across the world to measure service life of milking installation components. The only available devices are those for monitoring certain changes in functional properties (Mašková, Los 2000). Results from a range of tests indicated that the decisive parameters to determine service life could be as follows: capacity of working surfaces to be cleaned, resistance against the effect of cleaning and disinfection agents, change of materials physical properties, deformation of liners.

There are interactions between the milking machine and the lacteal gland of dairy cow in the process of milk acquisition by machine milking. The adviced hardness of liners should range between 50–55°Sh A. The hardness of synthetic rubbers is increasing in the course of exploitation due to the effects of cleaning and disinfection agents, milk and mechanical stress, and the increased liner hardness results in teat traumatization during milking (Mašková, Los 2000).

The problem was studied within the Grant MSM No. 432100001.

A milk tube with higher hardness represents a certain restriction for the operator at handling the milking machine because the tube flexibility is impaired.

As mentioned by some authors (O'CALLAGHAN, HARRINGTON 2000; GLEESON, O'CALLAGHAN 1998), the age of used liners and milk hoses can also impair milking rate, total milk yield, relative milk yield per 3 min, thus markedly influencing functional properties of the employed milking equipments. The above authors mention the functional properties to be also affected by the shape of liners.

MATERIAL AND METHODS

Proper study and verification of the effect of operational conditions and long-term influence of cleaning and disinfection agents on rubber components in the milking installation were made in two refurbished rotary milking parlours Melotte 9 employing milking machines with milking sets BDS-378.3 made by Agrostroj Pelhřimov, a.s., and milk collector volume of 420 cm^3 (UNILAC).

Cleaning and disinfection in the two milking units were made by automated washing units AMA 227.1 (Agrostroj Pelhřimov, a.s.) which had a facility enabling adjustment of water dosing according to the type of milking equipment and additional heating of cleaning and disinfection solution.

The used cleaning and disinfection agents were also applied for sanitation of milk cooling tanks.

For the purpose of temperature control during the main cleaning a temperature probe Temat 420 (M 20 × 1.5 – range of measured temperatures 0–100°C) was installed into the recurrent branch of each milking unit and temperature values in the course of the entire cleaning process were recorded by a two-channel recorder Z 144 made by Metra Blansko.

A time schedule was set up for observation and sampling of liners and milk tubes in order to verify the capacity of liners and milk tubes to be cleaned. Each sampling contained 4 liners of each type, and samples were taken from long milk hoses, whose length was 10 cm. The samples were then analyzed in accredited laboratories and obtained results subjected to a further statistic evaluation by UNISTAT 5.1 program.

The capacity of liners and milk hoses to be cleaned was tested by the smear method to the Standard ČSN 56 0082 *Food products. Principles for cultivation of microorganisms and the method of processing results in microbiological testing.* Individual smears were made by sterile tampons at all times after the main cleaning of the milking equipment. The wipings were assessed in the central laboratory Celab, a.s., Brno for total counts of microorganisms and counts of Coli-bacteria since it was necessary to take into account also a possible contamination by animal faeces.

The determination of hardness in international units (°Sh A) was carried out to the Standard ČSN ISO 48 *Rubber of vulcanized or thermoplastic synthetic rubbers. Determination of hardness (hardness between 10 IRHD and 100 IRHD).*

Table 1. Initial parametrs of tested liners

Manufacturer SN	Hardness (°Sh A)	Strenght (MPa)	Extensibility (%)
SN1	59	12.24	509
SN2	56	12.81	510

Specimens were cut out from a test sample of 2 mm in thickness. Measurements were made on the inner face of liners and milk hoses.

Strength and extensibility of rubber specimens were determined in the laboratories of ITS Zlín according to the Standard ČSN ISO 37 *Rubber made of vulcanized or thermoplastic synthetic rubbers. Determination of tension properties* similarly as the hardness determination.

Strength σ_r (MPa) is determined on a tearing machine with the specimen in a shape of two-sided blade is being stretched at a constant rate up to its breakage. The shape and dimensions of the specimen are defined by norm.

Extensibility ε_r (%) is determined on a tearing machine and calculated from the relation:

$$\varepsilon_r = \frac{l_r - l_0}{l_0} \cdot 100 \quad (\%) \qquad (1)$$

where: l_r – measured length of blade working part (mm),
l_0 – initial measured length of blade working part (mm).

The tests included two sets of liners, both based on acrylonitrile rubber. The first set of liners (SN) is marked as SN1 and the second set is marked as SN2. Parameters of new liners are presented in Table 1.

The cleaning and disinfection agents were based on sodium hypochlorite (alcaline) and phosphoric acid (acidic) in the cleaning and disinfection system A, and on sodium hypochlorite (alcaline) and amidosulphonic acid (acidic) in the cleaning and disinfection system B (Table 2).

RESULTS AND DISCUSSION

Obtained results were processed into tables for hardness, strength and extensibility analyses as depending on usage hours of liners and milk tubes in milking

Table 2. Detergents and disinfectants characteristics

Solution		Active substance	1% solution pH
A	alcaline	sodium hypochlorite	12.7
	acidic	phosphoric acid	1.8
B	alcaline	sodium hypochlorite, sodium hydroxide	12.2
	acidic	amidosulphonic acid, tensids	2.0

Table 3. Hardness, strenght and extensibility values for SN1

Manufacturer SN	Solution	Operational time (h)	Hardness (°Sh A)	Strenght (MPa)	Extensibility (%)
SN 1	A	0	59	12.2	509
		434	53	12.9	457
		728	53	13.8	552
		924	54	13.7	460
		1,218	57	14.0	454
		1,414	54	13.6	475
		1,610	54	13.8	539
	B	0	55	12.1	450
		574	48	12.9	447
		770	48	12.6.	460
		966	46	11.7	436
		1,162	45	13.9	469
		1,358	50	13.6	521
		1,554	50	13.4	476

(Tables 3, 4). Analyses to find out correlations followed in order to analyze the effect of usage time on the above mechanical properties. Next to determine were polynomial regressions of the 2nd order. An analysis of variance (ANOVA) was made to determine the measure of influence of the individual factors (liner type, cleaning agent, usage time).

It was found out through the evaluation of the results that there is a dependence of the liners strength on the usage time in SN1 and the cleaning and disinfection system A, when the strength is increasing with the increasing usage time. In contrast, a minimum dependence expressed by the value of the correlation coefficient is for usage time × extensibility and strength × extensibility.

Another close dependence was found in SN1 and the cleaning and disinfection system B for the dependence usage time × strength and strength × extensibility. In contrast, a minimum influence was found in the combination hardness × extensibility.

The greatest significant influence in the application of SN2 and the cleaning and disinfection system A was recorded for usage time × hardness and strength × extensibility. The lowest dependence was found for hardness × strength.

It is possible to conclude on the basis of the correlations that hardness would be increasing with the increasing usage time in the application of SN2 and the cleaning and disinfection system B. In other combinations of liners and cleaning/disinfection systems the

Table 4. Hardness, strenght and extensibility values for SN2

Manufacturer SN	Solution	Operational time (h)	Hardness (°Sh A)	Strenght (MPa)	Extensibility (%)
SN 2	A	0	56	12.8	510
		434	54	12.8	490
		728	54	13.7	512
		924	55	13.7	513
		1,218	56	14.2	465
		1,414	55	13.0	490
		1,610	58	13.6	481
	B	0	54	12.9	492
		350	46	13.7	491
		574	47	13.2	465
		770	47	13.8	480
		966	48	14.2	508
		1,120	45	12.4	431

Table 5. Regression analyses results; parameters of polynomial regression solutions of the 2nd order $y = a + bx + cx^2$

		Comb.	a	b	c	R^2	Significance
H	SN1	SN1-A	57.90	–0.0086	4.33E-06	0.4213	0.3349
		SN1-B	55.17	–0.0184	9.79E-06	0.8621	0.0190
	SN2	SN2-A	55.86	–0.0050	3.75E-06	0.7563	0.0594
		SN2-B	53.07	–0.0169	1.00E-05	0.7205	0.1478
S	SN1	SN1-A	12.18	0.0027	–1.09E-06	0.9096	0.0082
		SN1-B	12.15	0.0003	4.13E-07	0.4124	0.3453
	SN2	SN2-A	12.65	0.0018	–8.11E-07	0.4373	0.3167
		SN2-B	12.83	0.0033	–2.83E-06	0.3663	0.5045
E	SN1	SN1-A	510.77	–0.0821	5.10E-05	0.1176	0.7787
		SN1-B	448.57	–0.0200	3.31E-05	0.4486	0.3040
	SN2	SN2-A	507.20	–0.0014	–1.06E-05	0.3676	0.3999
		SN2-B	488.19	0.0222	–4.51E-05	0.2469	0.6536

Note: H – hardness, S – strenght, E – extensibility

hardness of liners decreases with the increasing time of their usage. In contrast, the strength of liners would be increasing in all cases of combinations of liners and cleaning/disinfection systems.

The last of the studied mechanical properties – extensibility is affected by the used type of liners. SN1 liners combined with any of the two cleaning/disinfection systems exhibit an increasing extensibility; SN2 liners – on the other hand – show a decreasing extensibility.

It was evidenced that the hardness of liners is highly significantly influenced only by the cleaning agent ($P < 0.01$). No significant influence on the value of hardness was evidenced in other factors or their interactions. The highest hardness values were reached in SN2 combined with the cleaning/disinfection system A (average 55.43°Sh A). The lowest mean values were rea-ched in SN2 and the cleaning/disinfection system B (47.83°Sh A). Parameters of regression equations (polynomial regression of the 2nd order) are presented in Table 5.

The values of liners strength were neither affected by any of the studied factors (liner type, cleaning agent, usage time) nor by their interactions. The highest mean values of strength were reached in the combination of SN1 and the cleaning agent A (13.44 MPa), followed by the combination of SN2 and cleaning agent A (13.40 MPa), and the combination of SN2 and cleaning agent B (13.37 MPa). The lowest strength values were reached in the combination of SN1 and cleaning agent B (12.89 MPa).

The last of the studied mechanical properties was extensibility. Its value was significantly affected ($P < 0.05$) only by the type of the cleaning agent. Other factors or their interactions did not exhibit any significant influence on its value. The greatest extensibility was found in the combination of liner type and the cleaning agent SN2 × A (average 494.36%), followed by the combination SN1 × A (492.29%), and by the combination SN2 × B (477.83%). The lowest mean value of extensibility was found in the combination SN1 × B (465.57%).

It follows from the above analyses and their results that the studied mechanical properties were most affected by the type of the cleaning agent and considerably less by the type of the liner.

The analyses did not allow to state with certainty what is the way of mutual dependence of the respective physical-mechanical properties in the used combinations of liner types and types of cleaning agents. For example – strength in dependence on hardness would be increasing with the exception of the combination SN2 × A, and extensibility in dependence on hardness would be decreasing for the cleaning agent A and increasing for the cleaning agent B. In contrast, hardness in dependence on extensibility would be decreasing in all cases while strength in dependence on extensibility would be increasing with the exception of the combination SN2 × A. Similar results were arrived at also by GÁLIK and KOVÁČ (2000).

CONCLUSION

Liners as the only ones come into the contact with the lacteal gland of the dairy cow thus having a direct influence on the quality of obtained milk and on the health condition of the cow. Increased hardness of liners results in a greater traumatization of teats during milking thus increasing the risk of mastitis. Increasing hardness of milk hoses has an impairing influence on handling the milker.

The measurements indicated that the changes of physical and mechanical properties as related to the usage time do not exhibit at all times the same tendencies. It is obvious that the usage time of liners must be assessed not only by the changes of physical-mechanical properties but also in the combination with other criteria such as deformations, capacity of working surfaces to be cleaned and release of black fillers from rubbers. Each of these criteria would put a limit on the usage time with decisive being the one of the limits that was reached first.

This is why it is necessary to continue the study and to carry on with another data analysis, which should bring an evidence of interactions between liners made by individual manufacturers and available cleaning and disinfection agents. The manufacturer has to guarantee a certain service life of products, which has been tested in practice. Laboratory tests such as accelerated ageing of rubber materials and swelling in cleaning and disinfection agents and the consequent changes of physical and mechanical properties do not correspond with the ageing during the actual operation. Laboratory conditions cannot sufficiently intercept the complex combination of environmental impacts and the mechanism of mechanical stress in milking.

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Vliv čisticích a dezinfekčních prostředků na fyzikálně-mechanické vlastnosti strukových návleček

ABSTRAKT: Fyzikálně-mechanické vlastnosti pryží se s dobou používání mění vlivem působení použitých čisticích a dezinfekčních prostředků, mléka a mechanického namáhání. Zvyšování tvrdosti strukových návleček způsobuje zvýšenou traumatizaci struků v průběhu dojení. Získané hodnoty tvrdosti, pevnosti a tažnosti byly analyzovány v závislosti na době používání. Zjistili jsme, že změna tvrdosti a tažnosti testovaných nitrilových strukových návleček nemá stejný trend pro použité čisticí a dezinfekční prostředky. Vysoce významně je tvrdost ovlivněna pouze použitými čisticími a dezinfekčními prostředky, které mají významný vliv i na tažnost. Naopak pevnost se s dobou používání zvyšovala ve všech případech a neprokázal se vliv žádného faktoru. Nejnižší hodnoty pevnosti byly u kombinace SN1 a čisticího systému B (12,89 MPa), nejvyšší u SN1 × A (13,44 MPa). Nejvyšší tvrdosti bylo dosaženo při kombinaci SN2 × A (55,43 Sh A) a nejmenší při kombinaci SN2 × B (47,83 Sh A).

Klíčová slova: struková návlečka; stárnutí pryže; fyzikálně-mechanické vlastnosti pryže; čisticí a dezinfekční prostředky

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Dependence of harvest yield of mushrooms on density of substrate

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ABSTRACT: Measurements were made to determine dependence of mushroom yield on density of substrate. Yields from individual containers were recorded from the beginning of the growth of fruit bodies. Mushroom yields at the lowest measured specific weight of substrate $\rho_S = 231$ kg/m^3 and at the highest measured specific weight of substrate $\rho_S = 531$ kg/m^3 were $P_P = 6.2$ kg/m^2 and $P_P = 10.9$ kg/m^2, respectively. This means that the specific weight of substrate increased by 301 kg/m^3 (i.e. by 43%) will result in yield increased by 4.7 kg/m^2 (i.e. by 57%). The measurement results corroborate the increased yield of common mushrooms per unit area in dependence on the increasing specific weight (compaction) of growing substrate within the range of achieved values.

Keywords: common mushrooms; yield; soil compaction; growing substrate

The growing of edible mushrooms is one of the youngest branches of special farm production and one of enterprising activities whose utilization can be an important contribution to the intensification of special agricultural production, larger assortment of food products, diversified human nutrition and possibilities of rational exports. Reserves that can be almost instantly used in this field are considerable.

The first publication about growing common mushrooms in our country was written by Růžimský in 1895 (GALUŠKOVÁ 1967) but the growing of mushrooms still remained on the level of occasional small-scale production even after World War I. WENZL (1968) mentions the first successful experiments with growing common mushrooms to have been made and first serious scientific information on them to have been presented by Landovský (1929). These were followed by works of Těšitel (1931), Smolák and Mikeš (1944) (WENZL 1968).

The original technologies of growing common mushrooms were conditioned by proper utilization of natural conditions which could create an optimum environment for the growth of mushrooms. The systems of growing mushrooms, initial treatment and substrate make-up vary and their development relates to production intensification. The chronological development of growing systems was featured by SMITH (1988) (Fig. 1). The first scientific description of methods for the growing of common mushrooms on ridges called "donkey backs" in abandoned limestone quarries and rock caves for the Paris market was presented by count de Tournefort (1707) in records of the French Royal Academy of Sciences (WENZL 1968). The system of shelves on walled supports was described already by Callow (1831) as mentioned by WENZL (1968). The shelf system was highly intensive but it began to be more used as late as after the year 1920. Mushroom growers in Pennsylvania, U.S.A. (FLEGG, SMITH 1980) designed and introduced wooden growing houses equipped with two rows of shelves which were 16–25 cm deep and about 1.8 m wide with 5 or 6 fields in a row. The box method of cultivation was first described in the patent of brothers Knaust from New York in 1934 (ATKINS 1966; KINRUS 1974).

The system of growing mushrooms in plastic bags was first used in Austria towards the end of the 1960s (RODWELL 1970). The idea of mechanized shelves came into existence nearly at the same time in the Netherlands (VEDDER, WOLTJER 1974) and in the U.S.A. The concept of growing common mushrooms on elevated beds appeared during the 1970s and its theoretical basis was the finding of Nielsen and Rasmussen (1962) (GALUŠKOVÁ 1967) that the mycelium of mushrooms is capable of transporting nutrients over a distance of nearly two meters. The main reason to develop the growing systems was first of all an effort aimed at the increased profitability and harvest yields.

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Table 1. Expression of yield dependence on the specific weight of substrate

Measurement	Compaction group	Container	Substrate weight M_k (kg)	Substrate weight M_p (kg/m^2)	Density ρ_S (kg/m^3)	Yield P_p (kg/m^2)
1	1	1	7.90	39.19	230.51	6.20
		2	8.60	42.66	250.93	6.10
		3	8.30	41.17	242.18	6.60
	2	4	11.20	55.56	326.80	6.60
		5	11.30	56.05	329.72	7.40
		6	10.60	52.58	309.29	9.10
	3	7	14.50	71.92	423.09	11.70
		8	14.30	70.93	417.25	10.60
		9	14.50	71.92	423.09	11.60
	4	10	17.20	85.32	501.87	11.80
		11	18.20	90.28	531.05	10.90
		12	17.50	86.81	510.62	14.70
2	1	1	8.20	40.67	239.26	6.20
		2	8.60	42.66	250.93	4.10
		3	8.30	41.17	242.18	5.40
	2	4	11.40	56.55	332.63	6.60
		5	11.60	57.54	338.47	7.80
		6	11.50	57.04	335.55	9.90
	3	7	14.65	72.67	427.46	11.80
		8	14.40	71.43	420.17	9.00
		9	14.80	73.41	431.84	9.50
	4	10	16.40	81.35	478.52	9.20
		11	17.90	88.79	522.29	12.10
		12	17.90	88.79	522.29	13.00
3	1	1	8.20	40.67	239.26	6.80
		2	8.80	43.65	256.77	9.20
		3	8.10	40.18	236.34	9.50
	2	4	10.40	51.59	303.45	10.80
		5	10.60	52.58	309.29	9.90
		6	10.50	52.08	306.37	13.30
	3	7	14.60	72.42	426.00	13.30
		8	14.20	70.44	414.33	11.40
		9	14.30	70.93	417.25	12.80
	4	10	17.50	86.81	510.62	15.50
		11	17.70	87.80	516.46	16.10
		12	17.30	85.81	504.79	20.50

It has been evidenced that another factor on which the yield of mushrooms depends is also the volume and compaction rate of the growing substrate.

MATERIAL AND METHODS

The observation was made in the mushroom farm Skalice, district of Frýdek-Místek, which was established in 1974 and employs the growing system of shelves with side supports. Substrate is handled by a system of belt conveyors and front-end loader.

Filling of containers

The growing substrate was filled into the PN-type containers of standard size 0.56 × 0.36 × 0.20 m. Diversified compaction was achieved by changing the substrate mass volume while the volume of growing containers was identical at all times.

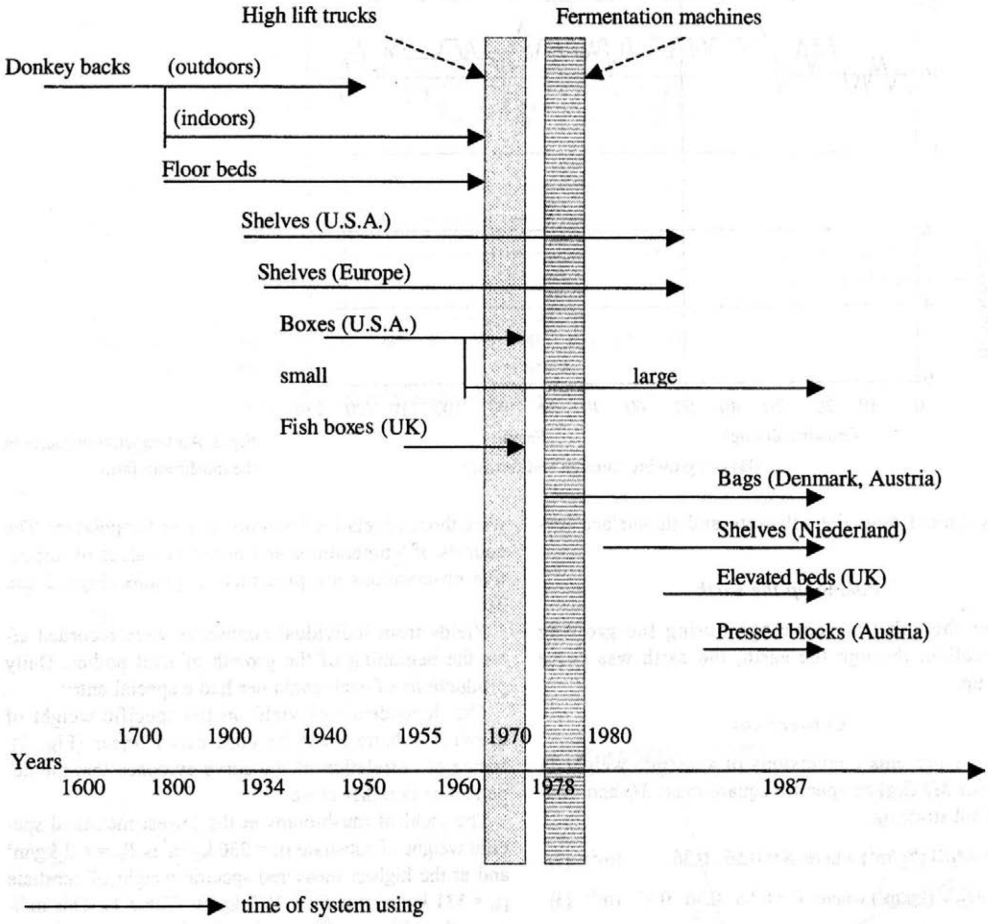


Fig. 1. The chronological development of growing systems (SMITH 1988)

Sterile environment in the container was ensured by lining the inner side with a foil which also served as a protection of substrate surface against drying out during the growth of mycelium.

Before filling the container it was first necessary to determine the minimum substrate mass volume which could be placed into the container and then the maximum possible mass volume at the maximum substrate compaction. The difference of these two volumes was divided into four compaction groups. In each of these groups the yield of mushrooms was measured in three containers with approximately same substrate mass volume (deviation ± 0.5 kg) which corresponded to the density of substrate ca. ρ_S = 230, 320, 410 and 500 kg/m^3. All mass groups were given three measurements.

The substrate in the container volume was compacted so that its height was 17 ± 1 cm. Substrate compaction and surface levelling were made with a wooden compaction implement whose surface was disinfected by charring before the proper work.

Growing of mycelium through the substrate

After filling the containers, the substrate surface was covered with a plastic foil and the containers installed in growing spaces where they were left until the entire substrate volume was grown through with mycelium.

Covering with earth

Covering by earth was made at the moment when all substrate was sufficiently grown through with mycelium, which showed in complete substrate coverage with white strings of mycelium. Earth layer height on the growing substrate was 3 ± 1 cm. Earth volume (V_y) necessary to cover the substrate was constant:

$$V_y = a_k \,.\, b_k \,.\, v_z \qquad (\text{m}^3) \qquad (1)$$

where: $a_k \,.\, b_k$ – floor space of container,

v_z – required earth height.

The earth volume to cover the growing substrate in one container was 7 litres. The gauging vessel was disinfected with 3% formalin solution. The earth was

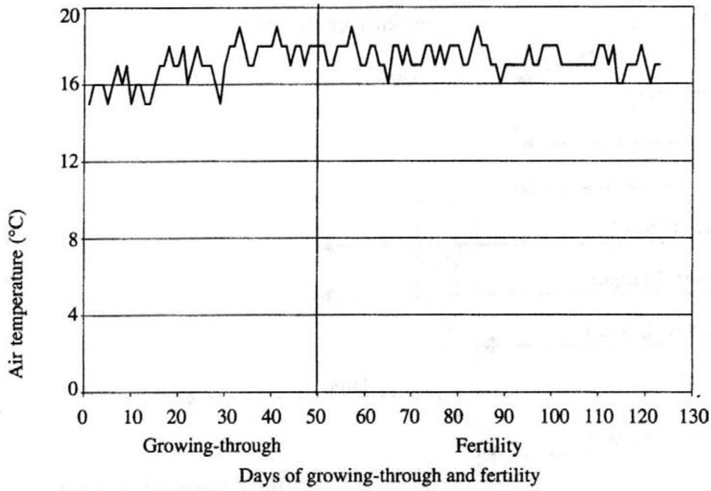


Fig. 2. Air temperature course in the mushroom farm

evenly spread onto the substrate and its surface levelled.

Raking up the earth

After the substrate coverage during the growing of mycelium through the earth, the earth was twice raked up.

Conversions

Table 1 presents conversions of substrate weight in container M_K (kg) to specific square mass M_p and density of substrate ρ_S:

$$M_P = M_K/S \text{ (kg/m}^2\text{) where: } S = 0.56 \,.\, 0.36 \quad \text{(m}^2\text{)} \quad (2)$$

$$\rho_S = M_K/V \text{ (kg/m}^3\text{) where: } V = 0.56 \,.\, 0.36 \,.\, 0.17 \quad \text{(m}^3\text{)} \quad (3)$$

Table 1 also presents conversions of mushroom yields from the container P_K to the square yield from 1 m^2 P_P.

$$P_P = P_K/S \qquad \text{(kg/m}^2\text{)} \qquad (4)$$

The converted values are illustrated in Fig. 4.

The dependence of mushroom yield on the specific weight of substrate can be fitted with a line of the following shape:

$$P_P = c + k.\rho_S \qquad \text{(kg/m}^2\text{)} \qquad (5)$$

where: c = 0.7301,
k = 0.0253.

For comparison, the values in Fig. 4 are also fitted with an exponential curve of the following shape:

$$P_P = b.\exp(a.\rho_S) \qquad \text{(kg/m}^2\text{)} \qquad (6)$$

where: b = 3.6492,
a = 0.0026.

RESULTS AND DISCUSSION

Measurements made during the growing of mycelium through the earth and during the growth of fruit bodies were those of relative humidity and air temperature. The courses of temperatures and humidity values of respective observations are presented in graphs (Figs. 2 and 3).

Yields from individual containers were recorded after the beginning of the growth of fruit bodies. Daily productions of each container had a special entry.

The dependence of yield on the specific weight of growing substrate can be considered linear (Fig. 4). Indice of correlation of the curve evidence that the dependence is rather close.

The yield of mushrooms at the lowest measured specific weight of substrate ρ_S = 230 kg/m^3 is P_P = 6.2 kg/m^2 and at the highest measured specific weight of substrate ρ_S = 531 kg/m^3 it is P_P = 10.9 kg/m^2 (Table 1). This indicates that the specific weight of substrate increased by 301 kg/m^3 (i.e. by 43%) will result in the yield of mushrooms increased by 4.7 kg/m^2 (i.e. by 57%).

CONCLUSION

The carried out measurements and analyses of results indicate that the specific weight (compaction rate) of growing substrate significantly affects the yield of common mushrooms. The above results of experimental research evidence the increased yield of mushrooms from unit area in dependence on the specific weight (compaction) of growing substrate. This dependence can be considered linear within the specific weight of substrate ranging from ρ_S = 231 kg/m^3 to ρ_S = 531 kg/m^3. The measurement results corroborate the increased yield of common mushrooms per unit area in dependence on the increasing specific weight (compaction) of growing substrate within by 4.7 kg/m^2 (i.e. by 57%).

The information can be practically used at optimizing the procedures of growing common mushrooms. The increased yield is naturally also resulting from the general approach to the observation of sound principles of mushroom growing. It is obvious that the yield of mush-

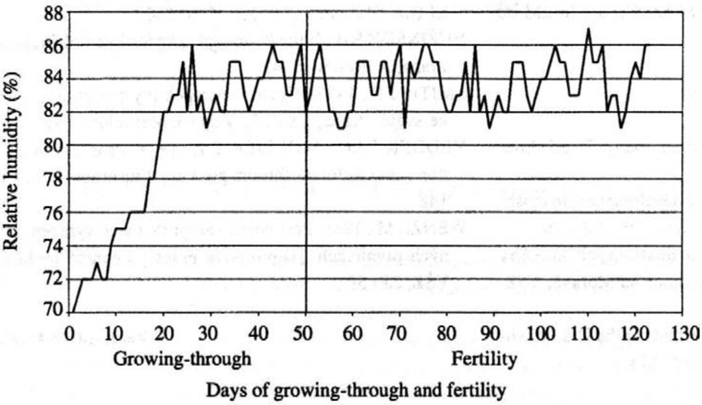
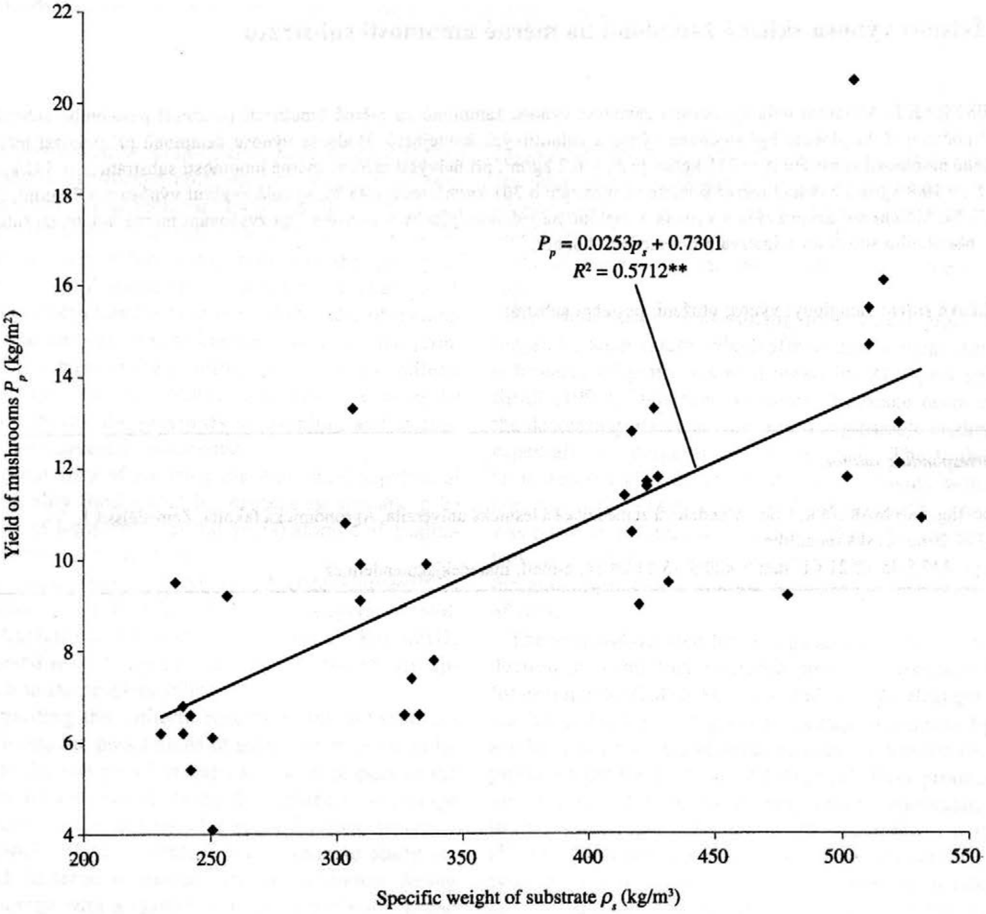


Fig. 3. Course of relative air humidity in the mushroom farm



	Regression function	Correlation index
Straight line	$P_P = 0.0253\rho_s + 0.7301$	0.7558**

Fig. 4. Yield of mushrooms in dependence on the specific weight of substrate

rooms depends on a number of parameters and growing conditions and whole set of effects exist that should be optimized to increase the yield.

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Závislost výnosu sklizně žampionů na měrné hmotnosti substrátu

ABSTRAKT: Měřením byla zjišťována závislost výnosu žampionů na měrné hmotnosti (utužení) pěstebního substrátu. Od počátku růstu plodnic byl sledován výnos z jednotlivých kontejnerů. Hodnota výnosu žampionů při nejnižší měřené měrné hmotnosti substrátu $\rho_S = 231$ kg/m^3 je $P_P = 6,2$ kg/m^2, při nejvyšší měřené měrné hmotnosti substrátu $\rho_S = 531$ kg/m^3 je $P_P = 10,9$ kg/m^2. Zvýšení měrné hmotnosti substrátu o 301 kg/m^3, tedy o 43 %, vyvolá zvýšení výnosu o 4,7 kg/m^2, tedy o 57 %. Měření dokazuje zvýšení výnosu žampionů na jednotku plochy v závislosti na zvyšování měrné hmotnosti (utužení) pěstebního substrátu v intervalu dosažených hodnot.

Klíčová slova: žampiony; výnos; utužení; pěstební substrát

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Effect of active ventilation on baking quality of wheat by long-term storage

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ABSTRACT: Supplies of even-quality food wheat can be ensured by using long-term (several years) storage with a possibility of active ventilation. The authors studied qualitative changes of baking properties in food wheat varieties for the period of 742 (530) days of storage. The quality parameters were currently measured in order to make final assessments of effects of variety, storage time and harvest year. An important parameter for baking qualities is the value of falling number. The studied varieties exhibited its increase with the exception of the variety *Hana* which showed a declining trend in dependence on the time of storage. The varieties *Asta*, *Brea*, *Bruta*, *Hana* and *Samara* had average values of falling number 320.85 sec (346.00 sec at the end of measurements), 293.50 sec (255.00 sec at the end of measurements), 284.88 sec (357.00 sec at the end), 332.85 sec (310.00 sec at the end) and 232.86 sec (243.00 sec at the end), respectively.

Keywords: viscotest; sedimentation test; gluten content; protein content; gluten index

The provision of even-quality food wheat supplies for year-long storage until the next harvest still appears to be a problem. Similarly, possible differences in the technological quality of wheat grain between individual years unfavourably reflect in the quality of manufactured products, especially in years with unfavourable climatic conditions at the time of maturation and harvest. Wheat breeders have to face problems in achieving the required quality, which reflects in realization costs. Another problem is to keep the quality during the processes of handling and storage until the moment of processing.

A possibility of ensuring the individual supplies of even-quality food wheat for processing appears to be the use of long-term (several years) storage of qualitative batches of food wheat.

The issue is being solved at the Mendel University of Agriculture and Forestry in Brno in cooperation with the Agricultural Research Institute in Kroměříž. Achieved results suggest usefulness of the chosen approach to the problem solution.

Regarding the hitherto results of the authors' research into the possibilities of using controlled ventilation at the storage of cereals, and with respect to the results of analyses studying the influence of storage methods on the quality of cereals for food products (Sychra, Hubík 1998), it was chosen to study selected, in terms of baking crucial parameters during the storage with a system of active ventilation. It can be assumed in connexion with previously found results (Mareček, Sychra 1999; Mareček et al. 2001) also for other crops (malting barley) that a maintenance of identical good or just slightly impaired quality of food wheat grain over the long-term storage can be ensured under observance of optimum conditions of the storage.

An important role at storing food wheat grain is played by temperature, which affects biochemical characteristics of grain. As mentioned by Rehman and Shah (1999), higher temperatures of storage result in the decreasing pH value and increasing titrable acidity, especially at temperatures above 25°C. The higher temperatures also bring about the decreasing water content in the grain, particularly so when the grain was put into the store with higher initial moisture content. In contrast, no significant biochemical changes of the grain were found at the lower storage temperature of 10°C.

The temperature used for storage also affects the production of respiratory microbial heat – as mentioned for example by Cofie-Agblor et al. (1997). Heat generation in the layer of grain at storage is induced by aerobic and anaerobic respiration with the aerobic respiration forming 91–97% of total heat. Heat production is higher at using higher temperatures, particularly for storage temperatures above 20°C combined with a higher moisture content. With storage temperatures being at the level of 10°C it has been evidenced that the heat production remains at a constant level for the whole time of the storage.

The above presented results and conclusions were achieved within the solution of the Grant MSM No. 432100001 funded by the Ministry of Education, Youth and Sports of the Czech Republic.

MATERIAL AND METHODS

Grain samples used for long-term storage were those of varieties *Asta*, *Brea*, *Bruta*, *Hana* and *Samara* from the harvest years 1997 and 1998. The wheat grain from the harvest in 1997 was stored for a total of 742 days and the samples from the harvest in 1998 were stored for 530 days. The grain of all varieties was put into bags made of air-permeable plastic non-woven textile material. The bags filled with the samples of 1 kg each were placed into the layer of grain in the silo at a depth of 0.5 m below the surface of the stored grain. The used storage chamber had a possibility of active ventilation during the storage.

The storage chamber capacity was 750 tons. The air volume supplied by ventilators was 0.23 m^3/sec. In the first 11 months of the study the system of active ventilation was operated at all times from 18.00 to 06.00 o'clock (air volume exchange was 6,652.8 m^3 for each chamber). In the following period, the ventilation was on for only two hours a day (air volume exchange being 1,663.2 m^3). In the last period of storage, the system of active ventilation was employed for 6 hours once in 14 days.

The temperature inside the grain layer ranged from 5 to 17°C during the experiment and the relative moisture content of grain was ranging from 13 to 14.5% with the value of 14.5% representing the initial moisture of introduced grain.

The wheat grain samples were gradually taken out from the bags and measured for following baking quality traits: falling number, sedimentation test, protein content, gluten content and gluten index. All analyses were carried out to the ICC standards (ANONYMOUS 1996) and AACC (ANONYMOUS 1995).

Significance of the effect of storage time, variety and harvest year on the studied parameters was evaluated by the analysis of variance and the measure of the effect of the given factors determined.

RESULTS AND DISCUSSION

Results from quality analyses were used to make an aggregative table (Table 1) with basic values characterizing the given quality trait average at the beginning of the experiment and at the end of measurements for the respective harvest years.

Falling number (viscotest) is one of important variables to assess food wheat quality, considerably affecting the quality of pastry. Activity of amylases, which is represented by this value, is very closely depending on the course of weather during grain ripening (HUBÍK, TICHÝ 1998). The fact was once again corroborated by our observations. The values of the criterion were also considerably contributed to by the effect of variety, which corresponded with the classification of wheats into groups by quality. While the effect of variety and harvest year in the mutual interaction reflected in the falling number, the value was not significantly influenced by the time of storage.

The highest falling numbers (viscotest) and hence the lowest activity of amylases was found in the variety *Hana* (max. 423 sec). On the other hand, the lowest falling numbers was exhibited by the variety *Samara* (max. 269 sec). However, the values are favourable and can be used by processing industries with no greater problems. While the falling number values in the varieties *Asta* and *Bruta* during the storage were increasing relatively markedly, the increase was less pronoun-

Table 1. Summary of monitored parameters by storage

Variety		Falling number (sec)	Protein content (%)	SDS test (ml)	Gluten content (%)	Gluten index (–)
Asta	start	269.00	11.10	60.50	24.70	84.00
	close – harvest 1997	346.00	11.90	46.00	26.10	89.00
	close – harvest 1998	401.00	13.03	49.00	22.10	86.00
Brea	start	282.00	11.40	75.50	30.15	76.50
	close – harvest 1997	255.00	11.90	75.00	27.40	87.00
	close – harvest 1998	350.00	13.03	61.00	32.20	79.00
Bruta	start	271.00	10.50	58.00	21.60	81.00
	close – harvest 1997	357.00	11.60	57.00	22.60	89.00
	close – harvest 1998	–	–	–	–	–
Hana	start	297.50	13.75	72.00	35.45	44.50
	close – harvest 1997	310.00	13.80	60.00	34.70	52.00
	close – harvest 1998	421.00	15.04	66.00	35.30	47.00
Samara	start	218.00	12.55	42.00	31.90	25.50
	close – harvest 1997	243.00	11.50	38.00	26.30	11.00
	close – harvest 1998	269.00	15.57	47.00	34.50	8.00

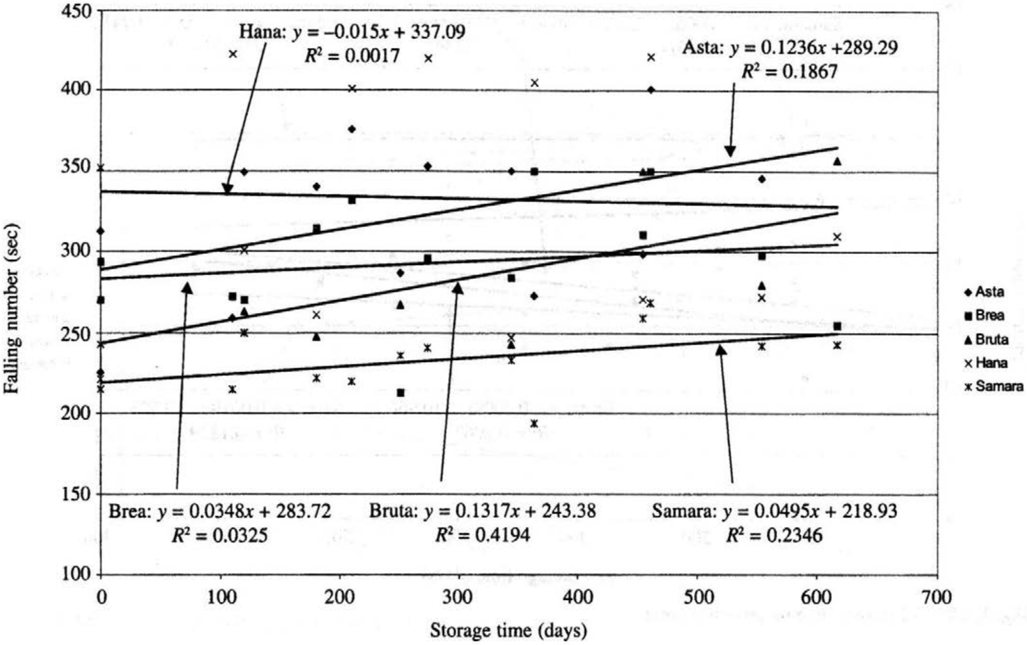

Fig. 1. Effect of storage time on falling number

ced in the varieties *Samara* and *Brea*, and the variety *Hana* exhibited decreasing values (Fig. 1).

Gluten content was statistically highly significantly affected by variety, which well corresponds with the used range of varieties. Significance of other factors (harvest year, time of storage) was not evidenced. Nevertheless, a high significance was found in the variety × harvest year interaction. The highest gluten content was found in the variety *Hana* (max. 38.3%) that was followed by the variety *Samara* (max. 37.1%), *Brea*, *Asta* and *Bruta*. Gluten content was slightly decreasing with the increasing storage time; a mild increase during the storage was detected only in the variety *Asta* (Fig. 2). The most conspicuous decline was detected in *Samara*.

Protein content corresponded with gluten content and was not significantly affected by any of the assessed

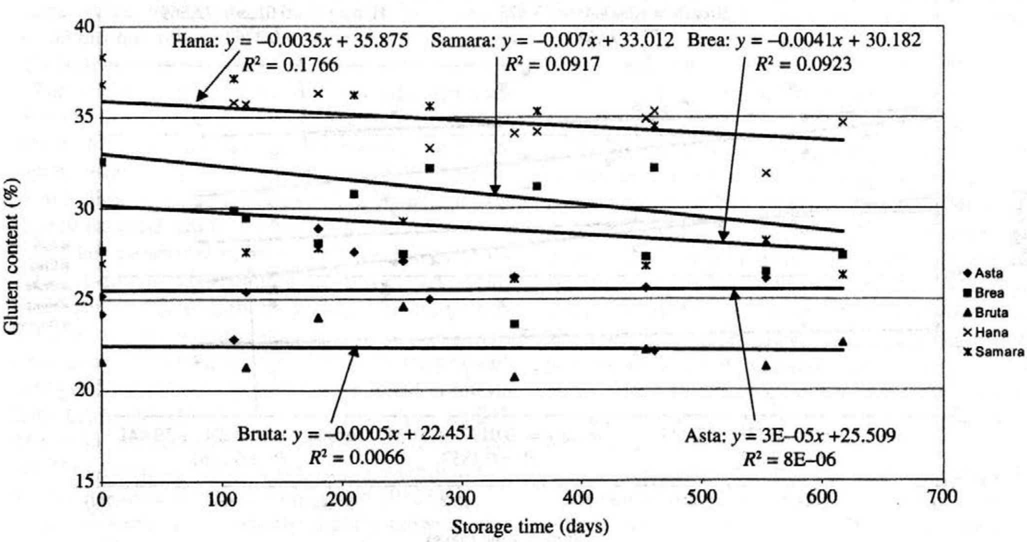

Fig. 2. Effect of storage time on gluten content

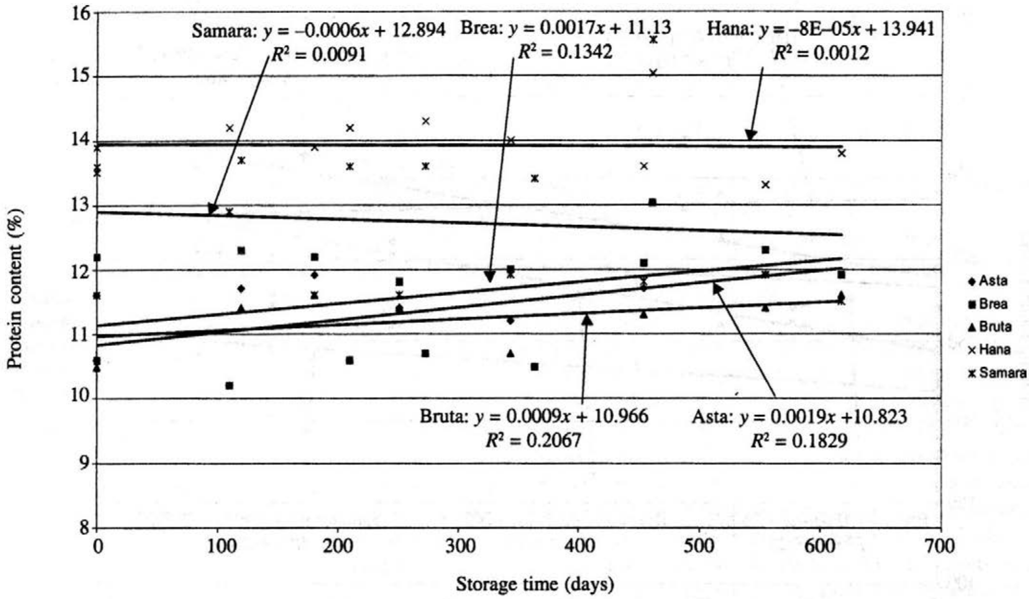

Fig. 3. Effect of storage time on protein content

factors, i.e. storage time, variety and harvest year. The highest protein content values were found in the variety *Hana* (average 13.92%), which corresponds with its classification as food wheat of high quality. The next best variety was *Samara* (average 12.73%). All other varieties had the average protein contents lower than 11.7% (Fig. 3). It should be pointed out at this place that the susceptibility of individual varieties to the cumulation of N-substances in the grain need not be always of conclusive importance. Considerably important is also the intensity of nitrogenous nutrition and availability of other nutrients (HŘIVNA et al. 1998). The content of nitrogenous substances fluctuated in the course of storage and did not exhibit any pronounced alterations. The variety *Samara* recorded a slight decrease.

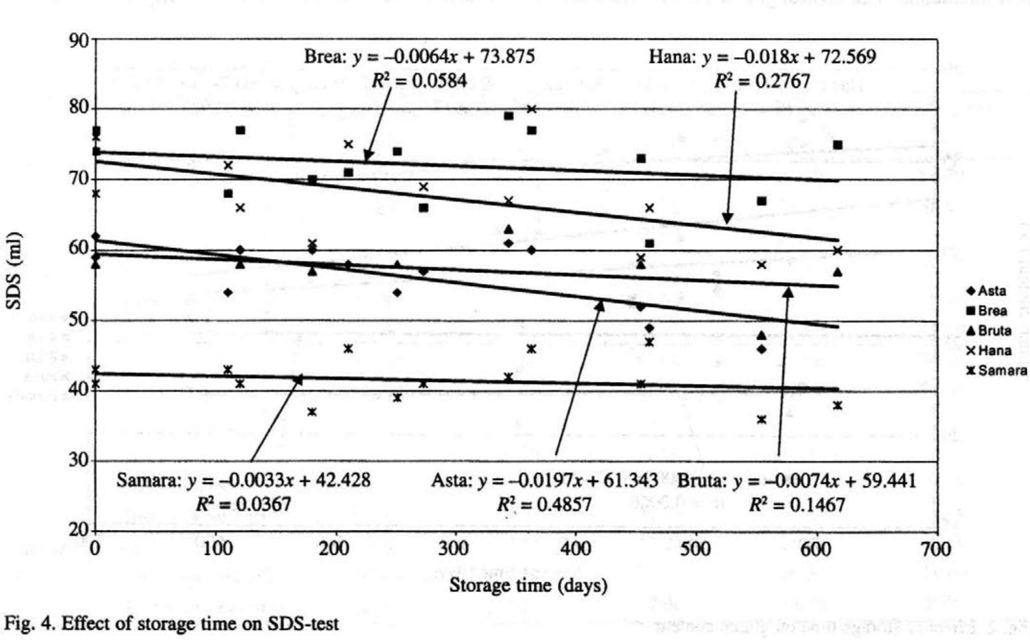

Fig. 4. Effect of storage time on SDS-test

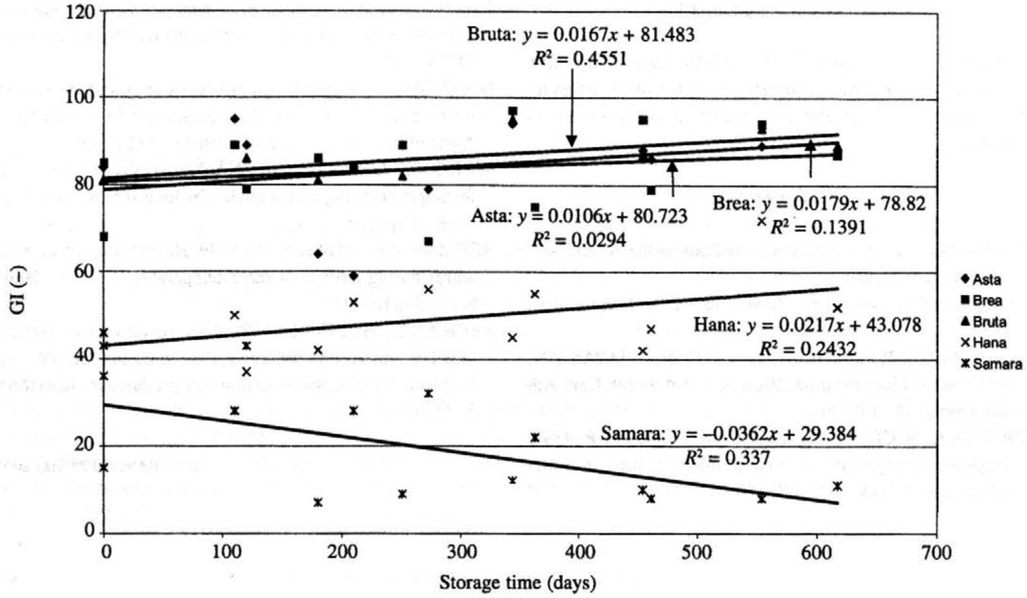

Fig. 5. Effect of storage time on gluten index (GI)

Sedimentation value (SDS test) that represents swelling capacity of wheat proteins did not entirely correspond with the recorded contents of N-substances and gluten. It was significantly affected and depending on the variety and considerably influenced also by the year of harvest. The two factors in mutual interaction shared in the values of this parameter. The highest values (Fig. 4) were shown by the variety *Brea* (72.07 ml) that was followed by *Hana* (67.46 ml). All remaining varieties had the value below 60ml with the lowest average value being found in the variety *Samara* (41.53 ml) that relates to its classification in the group of wheats improper for raised pastes.

The SDS test values in all varieties exhibited a decreasing trend in dependence on the time of storage. The most pronounced decrease was recorded in the varieties *Asta* and *Hana*; on the other hand, as indicated by the directive of regression balance equation, the slowest decrease was found in *Samara*.

The last parameter of wheat baking quality is the value of gluten index. Gluten index (GI) was highly significantly affected only by variety. The dependence of GI on the variety was more than obvious and closely corresponding with it. Gluten of the best quality with very good visco-elastic properties was found in the variety *Bruta* (86.75), *Brea* (83.86) and *Asta* (83.33). The value was markedly lower in the variety *Hana* (49.23) and the lowest average values were found in the variety *Samara* with running gluten (19.21).

The GI value was gradually slightly growing with the increasing time of storage, particularly in the varieties *Hana* and *Brea* as shown by values of regression equation directive. In contrast, the variety *Samara* exhibited a conspicuous decrease (Fig. 5).

It follows from the results that all quality parameters were highly significantly affected by variety with the exception of protein content. It was at all times a highly significant effect, expressed by significance lesser than 0.0001. Another factor that exhibited a significant influence on quality was harvest year or an interaction of the effects of variety and year of harvest. In contrast, the effect of storage time did not show in the majority of studied parameters and if so, it was in most cases their improvement.

CONCLUSION

The general view of food grain quality changes due to long-term storage does not suggest any serious or pronounced quality changes resulting from the method or time of storage. If the quality of food wheat is satisfactory, then it can be maintained over long time storage by means of active ventilation. With the rational control of storage processes combined with the targeted and purposeful use of active ventilation it was possible to ensure the reduced amylase activity of the grain, stabilization of N-substances with minimum changes in gluten content and swelling capacity of wheat proteins.

Varieties usable for baking exhibited improved visco-elastic properties of gluten protein. The use of storage method with the gradually restricted connection of active ventilation system appears to be a system suitable for long-term storage of cereals.

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Vliv použití aktivní ventilace na pekařskou jakost pšenice při dlouhodobém skladování

ABSTRAKT: Pro zajištění dodávek potravinářské pšenice o vyrovnané jakosti je vhodné použití dlouhodobého (víceletého) skladování s možností využití aktivní ventilace. Autoři prováděli sledování jakostních změn pekařských vlastností odrůd potravinářské pšenice po dobu 742, resp. 530 dnů skladování. Bylo prováděno průběžné sledování jakostních parametrů a vyhodnocen vliv odrůdy, doby skladování a ročníku sklizně. Pekařsky významným parametrem je hodnota pádového čísla. U sledovaných odrůd docházelo ke zvyšování tohoto parametru s výjimkou odrůdy *Hana*, která zaznamenala klesající trend v závislosti na době skladování. U odrůdy *Asta* byla průměrná hodnota 320,85 s (na konci sledování 346,00 s), u odrůdy *Brea* 293,50 s (na konci 255,00 s), u odrůdy *Bruta* 284,88 s (na konci 357,00 s), u odrůdy *Hana* 332,85 s (na konci 310,00 s) a u odrůdy *Samara* byla průměrná hodnota 232,86 (na konci 243,00 s).

Klíčová slova: viskotest; sedimentační test; obsah lepku; obsah bílkovin; gluten index

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New technology of electric power transmission

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ABSTRACT: Low cost and low losses single-wire electric power system (SWEPS) was developed. The new technology of electric power transmission uses idle operation regime of the transmission line and reactive capacitive current for transmission of active electric power. Three different SWEPS were constructed and tested: 230 V, 10 kV and 100 kV each is of one kilowatt capacity. Resonance mode of oscillation with frequency from 3 to 30 kHz was used to provide the most efficient power transmission. Frequency converter and modified Tesla transformer are applied at the generator site to generate high frequency reactive capacitive current. Reversal Tesla transformer and standard rectifier and invertor were used at the user's end to convert the reactive high frequency electric power to standard 50–60 Hz electricity. It was experimentally proved that SWEPS has quasi-superconductive properties for reactive capacitive current flow along the line even at high operation temperature of the electric conductor. SWEPS has no resistance losses for following tested conductor materials of the line: copper, aluminum, steel, tungsten, carbon, water, damp soil. The result of theoretical calculation and experimental study shows that SWEPS can be applied both for the energy transmission from renewable powerful generation site to a large energy system and for transmission lines for connecting different parts of renewable energy system.

Keywords: energy system; electric power transmission; high frequency conductor

Implementation of renewable-based technologies for rural electrification would contribute to the social and economic growth of the rural communities and would serve sustainable progress of the remote regions.

The electric grid faces specific problems of non-efficient operations, including transmission losses and the high cost of grid extension in remote sparsely populated areas (STREBKOV 1994). For example off-shore wind turbines, micro-hydro or geothermal generators are often located far from the consumer and require costly installation of long distance transmission lines which usually have from 6% to 10% electric losses.

Hybrid system, with jointly operating small power generators of equal capacity, faces the problem of joint electromagnetic operation stability during renewable energy potential or electric load variation.

We have made computer simulation of solar power system, consisting of three or more solar power plants of equal capacity connected by superconducting electric transmission lines. One solar power plant is located in Spain, another solar plant is installed in Far East region of Russia, the third one is situated in Astrakhan region near Caspian Sea.

The computer simulation shows that this distributed Europe-Asia solar power system is generating electricity 24 hours per day 6 months a year and it does not require electric accumulator or back up generator during the night. In winter season solar electricity should be transmitted from Africa, India and Australia and for this United Solar Electric Power System new low cost and low losses electric power transmission technology should be applied.

The objective of this paper is to introduce the low cost and low losses single-wire electric power system (SWEPS) for electric grid instead of three phase network.

THREE PHASE NETWORK FOR ELECTRIC POWER TRANSMISSION

It is known that the total transmitted power over electric transmission line

$$S = \sqrt{P^2 + Q^2} \tag{1}$$

where: P and Q – active and reactive powers.

The important parameter of transmission line affecting the energy transmission capability is surplus reactive capacity, which is depending on the regime of energy transmission. When the line operates in the idle regime its surplus reactive capacity is equal to the capacity of electrical the field of the line (ALEXANDROV, SMOLOVIC 1999):

$$P = 0 \quad S = Q = P_n \cdot l_\lambda \tag{2}$$

where: P_n – natural power which is equal to the surge impedance Z loading of the line.

$$Z = \sqrt{\frac{L_0}{C_0}} = vL_0 \tag{3}$$

L_0 and C_0 are the specific inductance and capacitance of the line.

l_λ – wavelength of the line, which is equal to the variation of wave phase during the wave propagation along line of length l

$$l_\lambda = \frac{\omega}{v} l = \beta l \tag{4}$$

where: $\omega = 2\pi f$,

f – frequency of generator,

β – the phase variation coefficient of the electromagnetic wave,

v – the velocity of electromagnetic wave propagation.

No-load operation mode is dangerous for electric power transmission because of voltage rise due to electromagnetic wave oscillation. When the generator frequency is equal to the resonance frequency of the line the overvoltage has maximum value. The voltage coefficient of the line

$$K_V = \frac{|\dot{U}_{max}|}{|\dot{E}|} = q \cdot |\dot{E}| \tag{5}$$

where: $|\dot{E}|$ – a generator voltage and q is the quality factor of the line.

In natural (nominal) regime of active electrical power transmission the magnetic field of the line completely compensates the electric field of the line and surplus reactive line capacity is equal to zero. In this ideal case reactive current and reactive power are equal to zero.

The angle Θ between vectors of voltage at the beginning of the line $\dot{u}(o)$ and at the end of the line $\dot{u}(l)$ is equal to wave length of the line, $\Theta = \beta l$.

The voltage is stable along the line $|\dot{u}(o)| = |\dot{u}(l)|$.

The active current and the active power transmission are controlled by variation of angle Θ and voltage along the line.

When a transmitted power is decreased and varies the compensation of electric field is not complete, the voltage will become higher and for its limitation shunt reactors are used to compensate the surplus reactive capacity of the line.

The equivalent circuit of this line is similar to series connection of active resistance and inductive impedance and such line has no wave and resonance characteristics.

Flexible alternative current transmission systems with fast acting shunt reactors and series capacitate compensation control system allows providing the stable energy transmission over the line length 1,000–3,000 km. The transmitted power is limited by resistance losses and by electrical isolation of the air. The installation cost of the 10–35 kV aerial transmission line is 10,000–25,000 US$/km.

A three phase a.c. 1.2 MV, 10 GW, 1,000 km long extra-high-voltage power transmission line costs 1.31×10^6 US$/km, and the whole power transmission system including transformer's substations and other electrical equipment has the installation cost 5.1×10^6 US$/km (MOGILLIS 1991).

Very costly direct current transmission lines for longer distance (7,000 km) and higher transmission capability (up to 70 GW) are proposed.

The installation cost of 10 GW, 1,000 km, ± 600 kv bipolar d.c. transmission line is 5.8×10^6 US$/km, and designed wasted power is 443 MW (4.43%). In future direct current transmission will provide even higher capability using advanced superconducting technology. The general conclusion regarding widely applied power transmission systems is that reactive power should be completely limited and compensated in order to provide stability of power transmission, to avoid the dangerous overvoltage and to secure the oscillation damping.

NEW TECHNOLOGY FOR ELECTRIC POWER TRANSMISSION

In this paper we consider new technology for electrical power transmission using idle operation regime and wattless capacitive circulating power for transmission of active power to the user's end of the line. In the open-ended line the active current and the magnetic field of the line are equal to zero, while the electric field has maximum value and it is created by the reactive displacement current which is charging the capacitance of the line. The angle Θ between voltage vectors at the beginning and at the end of the line is equal to zero.

Practically because we use the open-circuit line we offer one-pole single-wire electric power system (SWEPS) instead of three-phase network (AVRAMENKO 1997, 1998).

The most important problems, which are to be solved:

1. How to provide the high density reactive capacitive current at the beginning point of the line;
2. How to convert the reactive capacitance current and reactive power to active power and heat at the user's end of the line.

Schematic circuit of SWEPS is shown in Fig.1. Because the traditional three phase 50–60 Hz generators and other a.c. electrical equipment are widely used we offer electrical devices (black boxes), which can be installed at the beginning, and at the end of transmission line and can provide electromagnetic compatibility of new technology with standard a.c. electricity. Frequency converter and modified Tesla transformer with ferrite corn were applied at the generator site to generate high voltage and high frequency reactive electromagnetic power. Reversal Tesla transformer and standard rectifier and inverter were used at the consumer's end of high voltage SWEPS to decrease the voltage and to convert the reactive high frequency electric power to standard three phase 50 Hz electric power.

For proper operation of SWEPS it is necessary to connect the neutral primary voltage terminal of reversal Tesla transformer to artificial natural capacitance like an insulated metallic sphere or the frame of equipment.

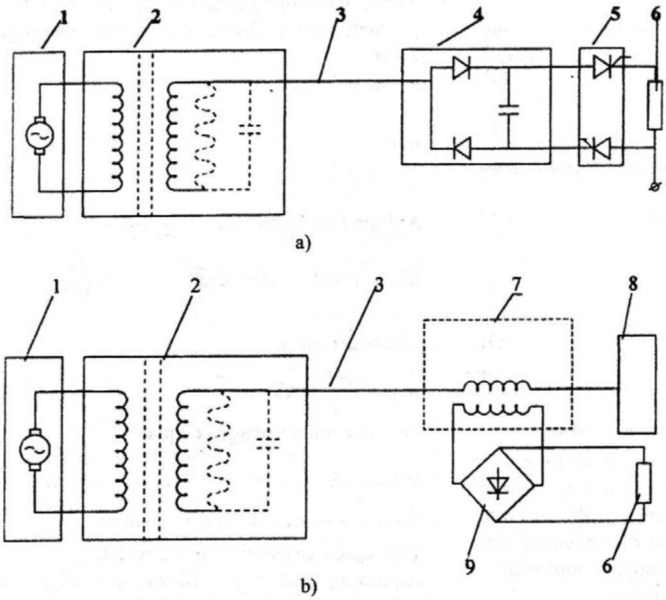

Fig. 1a. Low voltage single-wire line 10–1,000 V
1b. High voltage single-wire line 1–1,000 kV
1 – High frequency converter
2 – Step-up high frequency Tesla transformer
3 – Single-wire line 1–300 kHz
4 – Diode-capacitor block
5 – Thyristor electronic key
6 – Electric load
7 – Step-down Tesla transformer
8 – Electric capacitance
9 – Rectifier

A reactive capacitive current flows trough Tesla transformer and provide resonance overvoltage on its inductance impedance.

Another technique of conversion of capacitive reactive power to active power is application of diode-capacitor device which is usually used in d. c. voltage doubling circuit in low voltage SWEPS (Fig. 1b).

CALCULATION OF SWEPS PARAMETERS

In order to increase the transmitted power the operating frequency was significantly increased due to well-known equation for reactive power.

$Q = 2\pi fcU^2$

The quality factor, q at frequency 10 kHz is increased by 200 times comparing with 50 Hz power system. The upper value of frequency 100–300 kHz is limited by irradiation of electromagnetic power. Effective radiated power Pir of the unloaded line can be calculated using known formula for transmitter's antenna

$$Pir = 80\pi^2 I^2 \left(\frac{l}{\lambda}\right)^2 \qquad (6)$$

For $I = 100$ A, $\lambda = 30{,}000$ m, $l = 100$ m, $f = 10$ kHz, $Pir = 8 \times 10^{-3}$W

Consequently the radiated power is low at this frequency.

Let us consider a single-wire capacitive-inductive series resonant circuit without corona losses connected to the Tesla transformer without the magnetic shunt (Figs. 2, 3). As the line is open-ended the conduction current is equal to zero (Fig. 3). The Tesla transformer generates capacitive current, which is charging the capacitance of the line. For standard 50 Hz 500 kV line the capacitive current is 1.13 A/km, and reactive capacitive power is 0.98 MVAR/km. A single-wire overhead line capacitance is defined under the known formula:

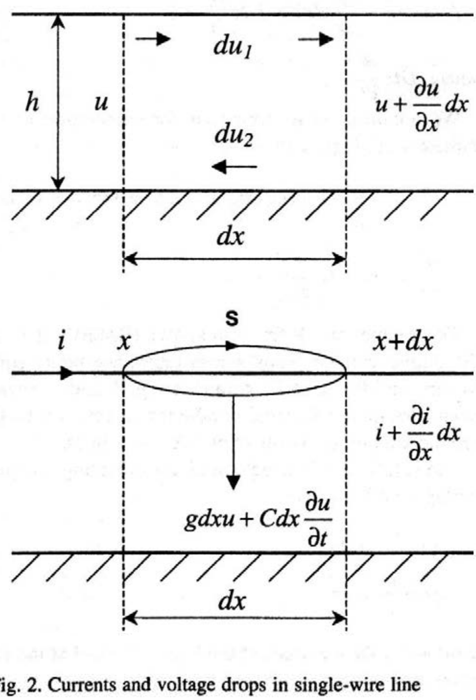

Fig. 2. Currents and voltage drops in single-wire line

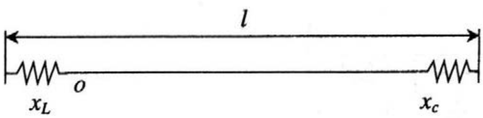

Fig. 3. Equivalent circuit of SWEPS

X_L – inductactive impedance of Tesla transformers and single-wire line

X_c – capacitance of the line and the load

$$C_o = \frac{l}{2\,ln\dfrac{4h}{d}} \tag{7}$$

where: l – the length of the line,
d – diameter of a conductor,
h – distance between the earth and conductor.

For $l = 1$ km, $d = 0.1$ cm, $h = 6$ m, Co = 15,505 mμF.

The open line is grounded through leakage current and displacement current, which are distributed on all space, enclosing a conductor. The displacement current and voltage depends on time and on coordinate.

The equation of continuity for current

$$(-i) + (i + \frac{\partial i}{\partial x}dx) + (gdxu + Cdx\frac{\partial u}{\partial t}) = 0 \tag{8}$$

where: $gdxu$ – leakage current,
g – conductance of air.

$Cdx\dfrac{\partial u}{\partial t}$ – displacement current.

The equation for voltages:

$$(-u + u + \frac{\partial u}{\partial x}dx) + Ldx\frac{\partial i}{\partial t} = 0 \tag{9}$$

where: $Ldx\dfrac{\partial i}{\partial t}$

We obtain a set of equations for calculation of parameters of single-wire line.

$$-\frac{\partial u}{\partial x} = L\frac{\partial i}{\partial t} \text{ – voltage drop across an inductive resistance.}$$
$$-\frac{\partial i}{\partial x} = gu + C\frac{\partial u}{\partial t} \tag{10}$$

These equations differ from known (RASEVICH 1976) the ohmic voltage drops across resistance being equal to zero and the specific parameters g, L and C having been considered for one conductor in relation to the ground but not for two-wire or three-wire lines.

The solutions of the equations for operating complex voltages and currents:

$$\dot{u}(o) = \dot{u}(l) \times ch\dot{\gamma}l$$
$$\dot{i}(o) = \frac{\dot{u}(l)}{z} \times sh\dot{\gamma}l \tag{11}$$

$u\,(o)$ and $u\,(l)$ – voltage at the beginning and at the end of the line.

As the line is open-ended the current $i(l) = 0$

γ – coefficient of electromagnetic wave propagation

$\gamma = \alpha + i\beta$

α – damping factor

$$\alpha = \frac{r}{2\sqrt{\dfrac{L}{C}}} \tag{12}$$

At high frequencies $\omega C > g,\ \omega L > r$

$$\alpha = 0 \quad \gamma = i\beta \qquad \beta = \omega\sqrt{LC} \qquad Z = \sqrt{\frac{L}{C}}$$

$$\dot{U}(o) = \dot{u}(l)\cos\beta x$$
$$\dot{I}(o) = j\frac{u(l)}{z}\sin\beta x \tag{13}$$

The maximum voltage is equal

$$U(l) = \frac{4}{\pi}qE \tag{14}$$

where: E – a voltage of Tesla transformer.

The capacitive current $Ic = 2\pi fCU$

Assuming $u(o) = E = 10$ kV, $q = 10$, $f = 5$ kHz, $C = 0.1$ μF, $u(l = 15\text{ km}) = 127.25$ kV

The capacitive current $Ic = 39.75$ A

The reactive power $Q = 2\pi fCu^2 = 5.08$ MVAR

Energy stored by the capacitor 0.1 μF.

$$E_c = \frac{Cu^2}{2} = 0.809kJ$$

Takeoff active power from capacitor transmitted through electronic key with switching frequency $fo = 1$ kHz $P = Ec \times fo = 0.809$ MW

EXPERIMENTAL RESULTS

Three different types of SWEPS were designed and tested: 230 V, 10 kV and 100 kV, each one being of one-kilowatt capacity. Tesla transformer has C-type unclosed magnetic circuit with ferrite core of 40–50 mm diameter. Secondary high voltage bobbin coil is wound upon ferrite core and it has 4–6 thousand of winding turns. One terminal of the secondary coil is in the center of secondary coil and from this terminal the current is taken to single-wire line. External neutral terminal of the secondary coil has a zero potential in relation to the ground. This neutral terminal is isolated.

Primary coil is wound around in proximity to the secondary coil. Primary coil has 40–50 winding turns. The terminals of primary coil are connected to frequency converter. SWEPS comprises two Tesla transformers, connected by single-wire line. Reversal step-down Tesla transformer at the user's end has the same structure of coils as a step-up Tesla transformer (Tesla 1900).

As a material of conductor copper, aluminum, steel, and tungsten were used. The diameter of wire is 5–100 microns. The transmitted power is 1 kW at voltage from 230 V to 100 kV. Diode-capacitor block comprises 0.25 μF, 16 kV capacitor. As a conductor also non-metallic conductive media were used, like carbon wire of 100m/km diameter with resistivity 100 Ohm/m, plastic water tube of 10 mm diameter, plastic saucer with 10 mm layer of damp soil, ITO conductive film on glass substrate. Conductive film has a resistivity 30 Ohm/m and a thickness of 0.3 microns.

The current, voltage and power of SWEPS were measured by standard 50 Hz devices at the beginning of the line.

As electric load appliances a.c. motors and filament lamp were used. The parameters of the load are measured by standard a.c. electric meters.

Single-wire circuit was tuned by frequency variation. At resonance mode the capacity of the load is at its maximum. The experiments showed that in resonance mode the current transiting to the load through set-down Tesla transformer in ten times exceeds a current transiting through the secondary coil and charging the natural capacitance. Transmitted power does not vary at any diameter and material of a single-wire circuit. The wire room temperature does not increase after several hours of power transmission. The powerful electric oscillation produces stationary waves in unloaded single-wire line.

The wavelength is defined by frequency of generator or frequency converter. But when the electric load is switched on, traveling waves appear. The reactive power transmission is carried out by electromagnetic field propagation along the line which one executes a role of guiding system.

Transmitted power of single-line-to-ground short is equal to zero because of a detuned circuit.

Resonant frequency is dependent on distributed capacitance and inductance of the Tesla transformer, the line and the load. At removal of ferrite core the resonant frequency was augmented by 2–3 times.

The Tesla coil generates also electromagnetic waves of 4–5 cm length, which is equal to diameter of secondary coil of a setup Tesla transformer. These waves were observed by connecting several series connected fluorescent lamps to the inner terminal of secondary coil. In the loaded line the transversal dark and light areas displaced. The size of each area was 2–3 cm. So the secondary coil of set-up Tesla transformer plays a role of spiral antenna, emitting electromagnetic waves. The wavelength is defined by the diameter of the resonator and waveguide, the functions of which are executed by secondary Tesla coil.

SWEPS includes mono-polar low loss single-wire line. In a spark-gap of loaded single-wire line there was a plasma discharge of reactive power. We called this reactive plasma as cold plasma. There is a great difference between cold plasma discharge of reactive power and arcing short discharge of two-wire line transmitting an active power.

If a water layer is included as part of the loaded single-wire line and a spark-gap is created between the conductor and the surface of water, the cold plasma discharge between conductor and water is initiated. This cold plasma discharge does not change the temperature of water and does not evaporate water during 30 minutes of operation of line. We use spring water as well as sea water and water seems to be an ideal superconducting material for capacitive reactive power transmission.

When arcing short was created by an active power in a spark-gap between water and standard 50 Hz two-wire line we could observe splashes and evaporation of water. The industrial electrode boiler is a good illustration of effective electric power conversion to heat.

The plasma discharge in spark-gap of unloaded single-wire line decreases and depends on natural capacitance of a body. Using this property of one pole single-wire line we develop cold plasma coagulator for application in medicine and chemistry (AVRAMENKO, STUPIN 1997).

DISCUSSION

The electrostatic analogy is one of the visual arguments of operation principles of SWEPS.

Transversal electromagnetic waves are propagated along the line and these waves can have any frequency, including zero. The structure of wave field in a transversal plane is identical to electrostatic field and stationary magnetic field. The step-up Tesla transformer generates during half-cycle the charges of high density and high electrostatic potential. The free charges are moving along the line from generator site with high potential to the user's end with small potential and this capacitive charging current is stipulated by Coulomb forces. These charges are moving on the surface of wire and this current is not affected by Joule's rule. So Tesla transformer is operating during one half-cycle as electrostatic generator continuously generating free charges and supporting high potential at the generator site. In the following half-cycle there is a change of the sign of charges, which are recharging the line capacitance but the potential difference between the generator and the end of the line is saved and charges of the other sign are moving along the line to the load.

A displacement current in the space surrounding the wire corresponds to change of an electric field strength. The displacement current as well as capacitive charging current is not affected by Joule's rule.

Another component of displacement current takes into account moving charges and polarization in dielectric surrounding a wire. Polarization losses can be used for direct conversion of idle power to heat. But this effect has quite different nature than Joule losses physics. We found out the very high temperature increase of fresh wood when we use it as a conductor material for loaded single-wire line.

This simple method can be used for fast wood drying and one can find a lot of materials, which can be used to provide heat from reactive electric power using polarization losses mechanism.

One hundred years ago Nicola Tesla has developed his apparatus for transmission of electric energy using single-wire technology (Tesla 1956). In 1900 there was no photovoltaic industry, radio engineering, laser technology and superconductivity. Now we better understand the theory and application possibilities of SWEPS. Nicola Tesla considered that one terminal of secondary and primary coil of step-up and step-down transformers must be connected to the earth. That means that single-wire line can be applied only to the power transmission along the earth.

Now we know that electric power can be transmitted to any body, not connected to the earth, for example, to air balloon, plane or even to satellite. We even do not need to apply a step-down transformer for single-wire power transmission (Fig. 1a) and we can use for power transmission non-metallic conducting media, like isolated water tubes, cables made from carbon or conducting oxides on glass etc. We developed SWEPS using laser beam as a single-wire line (STREBKOV et al. 1999a). Laser beam creates ionized conducting channel in the air with ionic concentration $10^{15}/cm^3$. Step-up frequency Tesla transformer generates high voltage (more than 1,000 kV) potential and traveling electromagnetic waves which flow along this conducting channel. At the voltage level of 1,000 kV the transmitted power may reach the value of 1,000 MW, depending on the frequency and capacitance of the load.

Another field of SWEPS application is the electric transport. We offer electric transport systems using hybrid electric car and public transport: bus, tram, trolleybus, metro, electric train using single trolley line, isolated from the earth (STREBKOV et al. 1999b). 5 W 12 V experimental model of single-trolley car was constructed and tested.

New principles of electric power transmission, using capacitive and displacement current in single-wire one pole circuit in future can be applied for construction of United Global Solar Electric Power System for the world.

CONCLUSIONS

– Single-wire electric power system for electric grid can be applied instead of three-phase network. SWEPS uses one pole single-wire open-tuned circuit, capacitive and displacement current for transmission of active power. Modified step-up Tesla transformer was applied at the generator site to generate high frequency reactive capacitive current. Reversal step-down Tesla transformer or diode-capacitor block was used at the user's end to convert high frequency reactive power to standard a.c. 50 Hz or d.c. electricity.

– Three different 1 kW capacity SWEPS were tested: 230 V, 10 kV and 100 kV. Resonance mode of oscillation with frequency from 5 to 15 kHz was used to provide the most efficient power transmission. The transmitted active power is proportionate to the frequency, capacitance of the load and quadrate of the load voltage. SWEPS and three-phase transmission line have the same parameter affecting energy transmission capability and this parameter is surplus reactive capacity of the line, which is equal to the capacity of the line's electrical field. So both lines have the same transmission capabilities in the range from 1 W to 10 GW. Both the predicted and observed electric losses of single-wire line are considerably less than the losses predicted for three-phase network. It is known from the theory of electricity that capacitive and displacement currents are not affected by Joule's rule. It was experimentally proved that SWEPS has quasisuperconducting property for capacitive and displacement current. SWEPS has insignificant resistance losses for following tested conducting materials: copper, aluminum, steel, tungsten, carbon, conducting ITO oxides on glass, isolated water tubes, damp soil. Conducting channel in the air ionized by laser beam was offered as a single-wire line for SWEPS.

– SWEPS is one of the most promising electric power transmission technologies for renewable-based electric grid. This technology may be recommended both for the power transmission from a powerful generation site to electric grid and for transmission line for joining together different parts of energy system. The computer simulation of distributed solar power system, consisting of several solar power plants installed in Spain, in European part of Russia and Far East of Russia, connected by low loss transmission line, resulted that this power system is generating electricity 24 hours a day 6 months a year and does not require electric accumulator or back-up generator during the night.

Another promising possibilities include single-trolley electric transport, isolated from earth and powered by solar power system, solar driven cold plasma generator and compact extra high voltage equipment.

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Nová technologie přenosu elektrického výkonu

ABSTRAKT: Byl vyvinut SWEPS, jednodrátový elektrický systém (elektrického výkonu) s nízkými náklady a ztrátami. Nová technologie přenosu elektrického výkonu používá režim přenosového vedení běhu naprázdno a jalový kapacitní proud pro převod činného elektrického výkonu. Byly zkonstruovány a otestovány tři různé SWEPS: 230 V, 10 kV a 1 000 kV jednotlivě s kapacitou 1 kW. Rezonanční vid oscilace s frekvencí od 3 do 30 kHz se použil pro maximálně účinný převod výkonu. U polohy generátoru pro výrobu vysokofrekvenčního proudu jalového výkonu byly použity frekvenční konvertor a modifikovaný transformátor Tesla. Na konci uživatele ke konverzi vysokofrekvenčního jalového elektrického výkonu na standard 50–60 Hz elektřiny byly použity reverzní transformátor Tesla, standardní rektifikátor a inventor. Bylo experimentálně dokázáno, že SWEPS má kvazisuperkonduktivní vlastnosti pro tok jalového kapacitního proudu ve vedení (elektrickém) rovněž při vysokých pracovních teplotách elektrického vodiče. SWEPS nemá ohmické ztráty pro následující testované vodičové materiály ve vedení: měď, hliník, ocel, wolfram, uhlík, voda, vlhká půda. Výsledek teoretických výpočtů a experimentální studie ukazuje, že SWEPS se může aplikovat jak pro přenos energie ze sítě produkce energie z obnovitelných zdrojů na větší energetické systémy, tak v přenosovém vedení pro spojení různých částí energetického systému s obnovitelnými zdroji.

Klíčová slova: energetický systém; přenos elektrického výkonu; vysokofrekvenční vodič

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SHORT NOTE

Uneven distribution of fenitrothion microcapsules (Detmol-mic) inside droplet deposits

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ABSTRACT: In microencapsulated pesticide formulations (SC) the active ingredient is not evenly distributed in spray fluid but is concentrated in plastic microcapsules. This note gives the first report of an aggregation tendency of fenitrothion microcapsules (Detmol-mic) inside of droplet deposit. In wet droplet, the highest proportion of microcapsules was separated and evenly distributed in the space while in dry droplets the microcapsules form aggregations. The influence of application method, either by pipette or hand sprayer, on aggregation pattern of microcapsules was negligible. Microcapsules aggregation inside droplets further increases the concentration and non-uniformity of active ingredient on the surface treated by this type of pesticide. The implication of aggregation effect of microcapsules for an insecticide "bioavailability", efficiency on target pest and a resistance prevention is discussed.

Keywords: pesticides; distribution; droplet size; aggregation

It is widely recognised that the distribution pattern of active ingredient in the treated area largely influences the efficiency of a particular pesticide treatment, rate of resistance development and level of an environmental contamination (COURSHEE 1991a,b; GOULD 1991). The influence of deposit structure on pesticides efficacy was studied extensively in field-crops (EBERT et al. 1999; EBERT, HALL 1999) but much less in the area of management of food industry and stored-product pests (ZHAI, ROBINSON 1992; STEJSKAL, AULICKÝ 2000). Generally, fluid pesticides are usually atomised with sprayers that deliver wide range of drop size. Consequently, droplets are contacted by arthropods crawling on the treated surface and the active ingredient is absorbed by cuticle (TSUDA et al. 1987). However, SALT and FORD (1984) found that the amount of pesticide picked-up varied considerably depending on the size of pesticide droplets and the age of residues. ZHAI and ROBINSON (1992, 1994) estimated critical number of dry pyrethroid droplets (0.1% cypermethrin – Demon EC) that must be contacted by legs of adult German cockroach to accumulate an individual lethal dose (LD). They found the LD = 300 droplets for non-resistant and 3,000 droplets for moderately resistant cockroach. These and other (e.g. EBERT et al. 1999) authors clearly demonstrate that the concentration of active ingredient, density and distribution of droplets substantially affect the control efficacy and economy of any residual insecticide treatment.

While testing the efficiency (STEJSKAL 1999) of some new encapsulated pesticides we notice that the microcapsules not always occur as single units. The above studies, while discussing various aspects of droplet distribution in detail, do not consider micro-distribution of active ingredient inside of single droplets. Therefore, the aim of this note is to give the first report of an "effect of intra-droplet aggregation" of insecticide microcapsules (Detmol-mic – fenitrothion) after their spray application, and discuss the implications of the "effect" for SC – pesticide efficiency.

METHODS AND MATERIALS

The fresh commercial sample of insecticide Detmol-mic (Frowein Gmbh) with microencapsulated (SC) fenitrothion (20%), as an active ingredient (a.i.), was used for the experiments. Detmol-mic is a formulation designed as a surface spray to control crawling pests in urban and stored product environment by its long-term residual effect. Two percent spray fluid of Detmol-mic, as recommended by a label instruction, was prepared by mixing a concentrate with distilled water as a diluent and shaken for 15 seconds thoroughly before each test.

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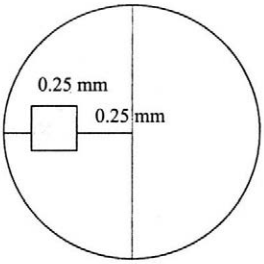

Fig. 1. Droplet area (i.e. dotted square 0.25 × 0.25 mm) where the distribution of microcapsules was measured

We compare the dispersion pattern of microcapsules (i) in wet droplet (WD) applied by a pipette (ii) in dry droplet (DD-P) applied by a pipette, and (iii) in dry droplet (DD-S) applied by a hand sprayer.

WD was obtained as follows: a droplet (0.04 ml) of 2% spray fluid of Detmol-mic was applied by a micropipette on the surface of the microscopic slide. The slide with a droplet was immediately put under a microscope at magnification 75× and photographed by a digital camera. The dispersion pattern was established from the photographs on 0.25 mm × 0.25 mm area as depicted in Fig. 1.

DD-P was obtained as in WD, but before counting microcapsules, the droplet was left dry for 2 hrs at 20°C.

DD-S was obtained by a spray of fluid on the horizontal glass surface covered by microscopic slides from the height of 30 cm. The application was made by a one stroke application (= 1.7 ml) of trigger gun hand sprayer. (In "trigger-gun" hand sprayer the pesticide and diluent are forced through the nozzle by pressure created when the trigger is squeezed.) After application the slides with droplets were left dry as in DD-P and after that the pattern of microcapsules aggregation was estimated.

The measurement of microcapsules distribution was repeated 6 times for each type of droplet (i.e. WD, DD-P and DD-S).

RESULTS

Fig. 2 demonstrates uneven size-spectrum of microcapsules in the Detmol-mic. Fig. 3 (A,B,C) shows the patterns of intra-droplet distribution of microcapsules in various droplet design: in wet droplet (WD) the major proportion of microcapsules was separated and evenly distributed while in both type of dry droplets (DD-S, DD-P) the microcapsules tend to aggregate. The influence of application method (spray or pipette) on aggregation pattern was negligible as demonstrated in Fig. 3B,C. In DD-S and DD-P the microcapsules aggregation form chains or "clouds", and, typically, many small microcapsules aggregate around a large one.

DISCUSSION

In this study we find that the intra-droplet distribution of microencapsules depends on whether the droplet is dry or wet. In spray fluid and wet droplets of Detmol-mic the aggregation of microcapsules is very low, probably due to a presence of organic solvents, surfactants and water. However, we observe that drying process of droplet deposits is followed by strong intra-droplet aggregation of microcapsules. Since many small microcapsules aggregate around large ones (Fig. 3B,C) we suspect that uneven size of microencapsules (Fig. 2) may promote their aggregation.

The microencapsulated insecticides (SC) have been used for almost 10 years in Czech Republic (STEJSKAL, VIŠNIČKA 1993) as well as in other regions of the world (TSUDA et al. 1987) and become the most commercially successful pesticides for control of public health and stored-product pests. According the information of the largest distributor of "speciality pesticide products" in Czech and Slovak Republic (PLACHÝ, pers. commun.), the microencapsulated organophosphates (not including Detmol-mic) have been largely the best selling product for the control of public health pests during the past decade. The success of SC-pesticides has been based, besides their (i) excellent residual activity, on the

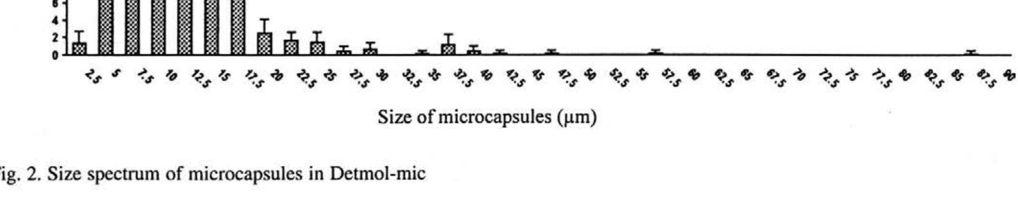

Fig. 2. Size spectrum of microcapsules in Detmol-mic

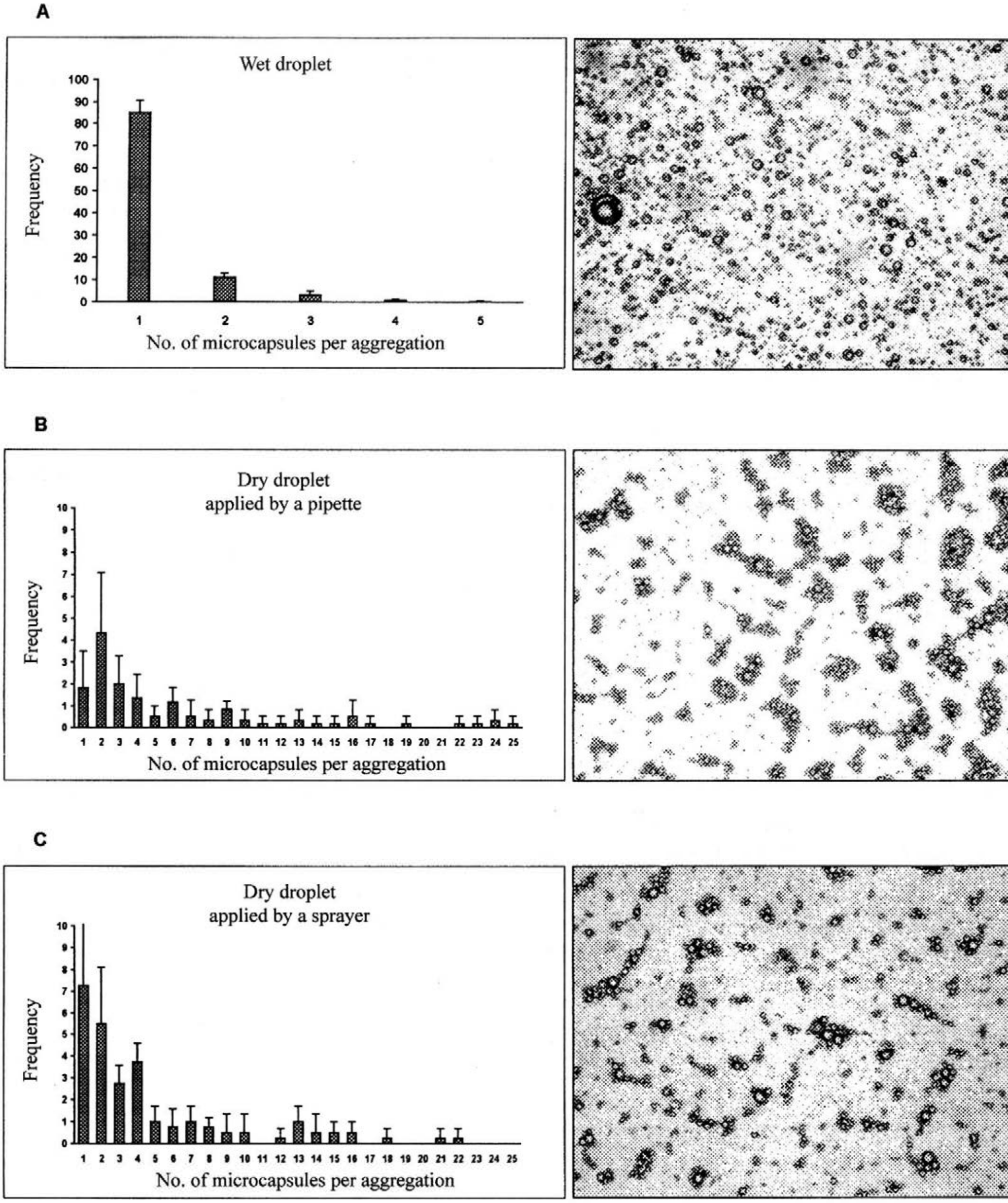

Fig. 3. Illustration (right) and frequency (left) of microcapsules aggregation inside of: A – wet droplet, B – dry droplet applied by a pipette, C – dry droplet applied by a sprayer

fact that (ii) no economically important level of resistance have been traced so far. Therefore, SC formulation must have some unique property in comparison with other formulation such as emulsifiable concentrates (EC).

Traditionally, it is believed that uniform distribution of small droplets gives most successful pest control results. That is probably the reason why one can not read anywhere that the technology of microcapsulation inherently cause uneven distribution of active ingredient on the treated surface. Such claim would be contradictory to the prevalent "even distribution = good efficacy" doctrine since microencapsulated pesticides are efficient. However, recently EBERT et al. (1999) and EBERT and HALL (1999) demonstrated surprising results indicating that uniform pesticide coverage of crops is not the best deposit structure if one is forced to limit application rates. Since uniform deposits structures allow an insect live longer and also should result in acquiring sub-lethal doses. Although not mentioned by these authors their findings may also explain the historical success of the microencapsulated (SC) over other spray (e.g. EC) pesticide formulations in the area of control of urban and stored product pests. ZHAI and ROBINSON (1992) give precise estimate of how many EC droplets of cypermethrin must be contacted by a cockroach to provide its kill. However, as the differences in efficiency of various formulations indicate, the outcome of the interaction between pest and certain No. of droplet of particular active ingredient also depends on the distribution of active ingredient inside the droplets. Droplets with evenly distributed "dry film" of emulsion (EC-formulation) have different activity then those where the active ingredient is concentrated into "high-dose" encapsules: WICKHAM (1995) concludes that microencapsulated product and wettable powders generally offer more readily available insecticide then solution or emulsifiable formulation – some times referred to as greater "bioavailability". Since the greater amount available and the easier it is for cockroach to pick-up, the more effective will be the application. Our finding that microcapsules aggregate inside droplets reveals another physical property of SC-formulation, which is connected with further increase of concentration and non-uniformity of active ingredient on the treated surface. Using WICKHAM (1995) terminology, the aggregation of microencapsules inside droplets may further increase the "bioavailability" of the active ingredient. In SC-pesticides the active ingredient does not occur freely in spray fluid but is concentrated into relatively "large" plastic microcapsules and after application, the target animal receive a high dose of active ingredient by trampling several microcapsules (TSUDA et al. 1987). Although the capsule walls are made sufficiently thin to be easily ruptured by passing cockroaches (WICKHAM 1995) the plastic shell are as well as prepared in way to ensure a long term residual activity due to protection of active ingredient inside microencapsules from degradation. Thus the encapsulation and concentration of pesticide, together with the aggregation of microcapsules and low degradability creates either (high dose) –or (nothing) "contact situation". Logically, "either–or" situation decreases the probability that the pest population meet the sublethal dose of pesticide (EBERT et al. 1999), which is a one of the general conditions for the slowing of the resistance development. In addition, concentration and aggregation properties of SC-pesticides may also contribute to "overdosing" or "saturation" effects that are also listed as anti-resistance strategies.

Thus the droplet spatial and size variation and the intradroplet arrangement of microcapsules may contribute to the "final pattern" of distribution of active ingredient on the treated surface, which has to be considered while modelling pesticide activity on a particular pest species. The distribution of aggregation inside of droplets (especially their centre-to-edge gradient) and the comparison of aggregation patterns of various commercial SC-formulations needs further study.

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Nerovnoměrné rozmístění mikrokapsulí fenitrothionu (Detmol-mic) uvnitř kapénkových depozit insekticidu

ABSTRAKT: V mikroenkapsulovaných formulacích pesticidů (SC-pesticidy) není aktivní látka rovnoměrně rozptýlena v emulzi, ale koncentrována do plastových mikrokapsulí. Tato práce poprvé dokumentuje agregační tendenci mikrokapsulí s fenitrotionem (Detmol-mic) uvnitř kapénkových depozit. V postřikové jíše a mokrých kapénkách jsou mikrokapsule rozptýleny rovnoměrně, zatímco v uschlých kapénkách dochází k jejich agregaci. Vliv aplikační metody na agregační chování mikrokapsulí v uschlých depozitech testovaného SC-insekticidu je zanedbatelný. V práci je diskutován agregační efekt mikrokapsulí na účinnost SC-pesticidů a na zpomalení vzniku rezistence škůdce.

Klíčová slova: pesticidy; distribuce; velikost kapének; agregace

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Materiál a metody: Model pokusu musí být popsán podrobně a výstižně. Popis metod by měl umožnit, aby kdokoli z odborníků mohl práci opakovat. Zkratky jsou používány jen pokud je to nutné; první použití zkratky musí být uvedeno úplným popisem nebo vysvětlením. Používané měrové jednotky musí odpovídat soustavě měrových jednotek SI.

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Diskuse obsahuje zhodnocení práce. Je přípustné spojení s předchozí kapitolou (Výsledky a diskuse).

Poděkování se uvádí před přehled použité literatury.

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