ANALYSIS OF HEAT EFFICIENCY OF THE RECUPERATION EXCHANGERS IN MICROCLIMATE EXACTING STABLES

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This contribution includes results of the recuperation exchangers investigation from gravitational heat tube utilizing secondary heat of the stable ventilation air for 13 000 chicken broilers. The results obtained have enabled to make accurate and analyse the methods of thermal and enthalpy exchangers efficiency related to the heat losses decreasing by forced ventilation and also to specify the heat-changing surfaces impurity effect onto heat recuperation change effectiveness from the ventilation air during the breeding period. It have also been proved necessity to use filters before the heat-changing surfaces withdrawn from the stable and their regular cleaning influence into the exchangers efficiency.

stable; thermal losses of ventilation; thermal balance; recuperation exchanger; gravitational heat tube; thermal efficiency; enthalpy efficiency

INTRODUCTION

Application of secondary (refuse) heat of the ventilation by means of the recuperation exchangers will considerably reduce energy consumption for heating and provides requested quality of the stable environment from the point of view of relative air humidity and harmful substances content at constant interior temperature. The application effectiveness of the secondary heat of the stable ventilation air has a substantial impact on the thermal losses by ventilation and is being affected by the exchanger construction, volume flows of the ventilation air, interior and exterior temperature, specific air humidity and dust particles content.

Most of foreign scientific and professional publications is focused to thermal conditions and efficiency of various recuperation exchangers in objects for pigs and calves rearing. Due to relative low dust content, as well as required air temperature, in these objects there are favourable operative conditions to utilize these exchangers. Barbari and Valli (1985) observed possibilities of the board recuperation exchangers utilization in both sow artificial insemination stable and in calf-house. The heat tube exchangers were investigated in some piglet houses. The board cross-current recuperation exchanger was tested in piglet houses and piggeries (Christianes, Meulen, 1985). In both publications the authors determined thermal efficiency of the exchangers. The heat exchanging surfaces pollution effect to the recuperation efficiency had not been investigated, apparently with regard to the feeding technology and animals housing. Harp and Huhnke (1990) investigated the exchangers utilization to back heat acquisition from piggeries ventilation air.

Research investigation of the recuperation exchangers in dusty, microclimate exacting environment was realized by Berlin Construction Academy in large-scale broilers fattening station VEB KIM Königswüsterhausen (Hettwer, Bath, 1982). It concerned exchanger assembled from 48 gravitational heat tubes, each 2 m long, arranged in 8 rows. At basic air flow velocity 3 m.s^{-1}, the exchanger reached the heat efficiency 43%. The heat-exchanging surfaces pollution effect on exchanger efficiency is not presented. In Czech Republic 2 recuperation exchangers assembled from gravitational heat tubes in relative difficult operative conditions of piglet house with dry feedstuffs were verified (Kára, Štulc, 1989). The exchangers assembled from 50 and 100 heat tubes, each 2 m long, arranged in 5 and 10 rows, were equipped with textile filters (flannel), installed in the air-drawn off side. The filters purpose is to protect the heat-exchanging surfaces against pollution. The heat efficiency within short-period testing reached values 0.43–0.48. The authors recommended to use these filters in practice.

Literature observance indicates that recent knowledge of recuperation exchangers operative regimes in livestock production objects do not enable to answer the questions about exchangers operative efficiency changes. Therefore, the aim of this paper is to verify and to analyse possibilities of the gravitational heat tubes exchangers utilization from point of view of operative efficiency of back heat acquisition by ventilating air in very dusty and qualitatively exacting chicken broilers fattening stable.

MATERIAL AND METHODS

Theory

Efficiency of the system for the heat recuperation from the ventilation air is generally defined by ratio between recuperated heat output and total output,

which may be obtained in case, when complete heat drop between interior and exterior air could be used:

$$\eta_R = \frac{Q_R}{Q_i - Q_e} \quad (-) \tag{1}$$

where: Q_R – obtained (recuperated) heat efficiency (W)
Q_i – inner drawn-off air heat efficiency (W)
Q_e – inner coming-in air heat efficiency (W)

When parameters of interior drawn-off air and exterior coming-in air are marked according to Fig. 1, then in the equation (1) in case when the drawn-off air is cooled above temperature of its dew point, i.e. $x_{i1} = x_{i2}$:

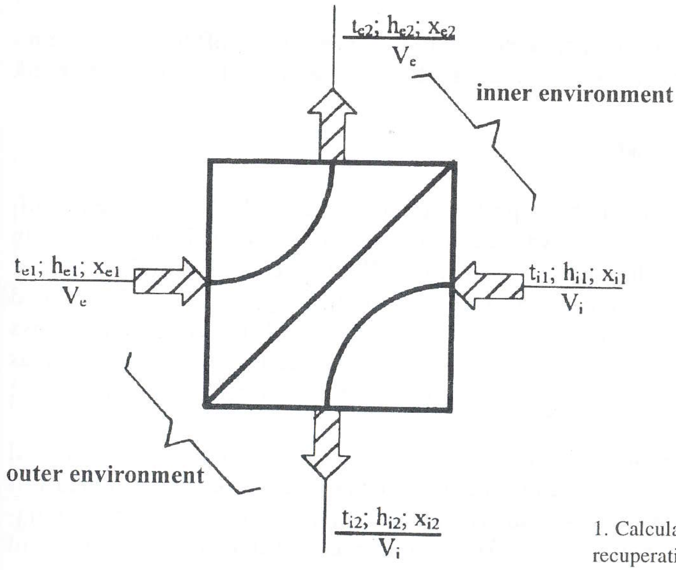
$$Q_R = V_e\,[(\rho_{e2}\,.\,c_{pe2}\,.\,t_{e2}) - (\rho_{e1}\,.\,c_{pe1}\,.\,t_{e1})] \quad (\mathrm{W}) \tag{2}$$

$$Q_e = V_e\,.\,\rho_{e1}\,.\,c_{pe1}\,.\,t_{e1} \quad (\mathrm{W})$$

$$Q_i = V_i\,.\,\rho_{i1}\,.\,c_{pi1}\,.\,t_{i1} \quad (\mathrm{W})$$

where: V – volume air flow (m^3.s^{-1})
ρ – air specific weight (kg.m^{-3})
c_p – specific heat air capacity at constant pressure (J.kg^{-1}.K^{-1})
t – air temperature (°C)

Assuming, that $\rho_{e1} = \rho_{e2} = \rho_e$; $c_{pe1} = c_{pe2} = c_{pe}$; $\rho_{i1} = \rho_i$; $c_{pi1} = c_{pi}$, the thermal efficiency η_{Rt} is expressed by:



1. Calculating scheme of the recuperation exchanger

$$\eta_{Rt} = \frac{t_{e2} - t_{e1}}{\dfrac{V_i \,.\, \rho_i \,.\, c_{pi}}{V_e \,.\, \rho_e \,.\, c_{pe}} \,.\, t_{i1} - t_{e1}} \quad (-) \qquad (3)$$

If the equal-capacity ventilating system is $V_i \,.\, \rho_i \,.\, c_{pi} = V_e \,.\, \rho_e \,.\, c_{pe}$, then the known relation for thermal efficiency η_{Rt} (Spalding, Taborek, 1983) is obtained:

$$\eta_{Rt} = \frac{t_{e2} - t_{e1}}{t_{i1} - t_{e1}} \quad (-) \qquad (4)$$

At the partial condensation of water vapour contained in inner drawn-off air, when $x_{i1} > x_{i2}$:

$$Q_R = \frac{V_e \,.\, \rho_{e1}}{(1 + x_{e1})} \,.\, (h_{e2} - h_{e1}) \quad \text{(W)} \qquad (5)$$

$$Q_i = \frac{V_i \,.\, \rho_{i1}}{(1 + x_{i1})} \,.\, h_{i1} \quad \text{(W)}; \qquad Q_e = \frac{V_e \,.\, \rho_{e1}}{(1 + x_{e1})} \,.\, h_{e1} \quad \text{(W)}$$

where: h – specific air enthalpy (J.kg^{-1})
x – specific air humidity (kg.kg^{-1} s.o.)

Presuming again $\rho_{e1} = \rho_e$; $\rho_{i1} = \rho_i$, then the enthalpy efficiency η_{Rh} is:

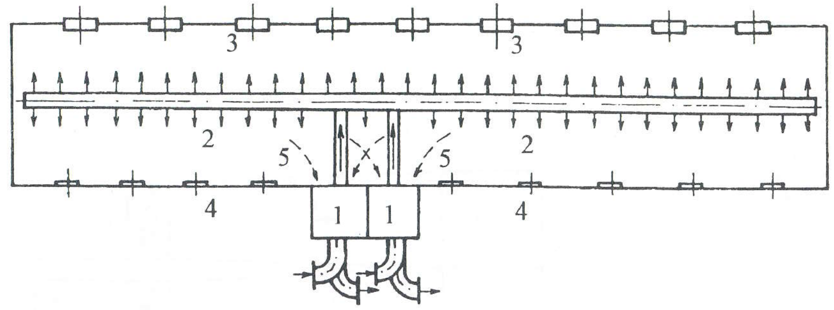
$$\eta_{Rh} = \frac{h_{e2} - h_{e1}}{\dfrac{V_i \,.\, \rho_i}{(1 + x_{i1})} \,.\, \dfrac{(1 + x_{e1})}{V_e \,.\, \rho_e} \,.\, h_{i1} - h_{e1}} \quad (-) \qquad (6)$$

To calculate specific parameters of both cooled drawn-off and heated coming-in air, generally known relations (Recknagel et al., 1994) were used.

Experimental Methods

The verification had been performed in stable for 13 000 chicken broilers fattening. The object was reconstructed from cowshed for 97 cows in vicinity of the village Čestín, the Kutná Hora district. The stable interior ground plan dimensions are 58 x 10.8 m and its height is 3.2 m. Calculated outdoor temperature of area is –15 °C, altitude 250 m. Specific heat loss due to the heat passage through object constructions was measured as 0.689 W.m^{-3}.K^{-1}. The heat loss produced by air infiltration by natural ventilation is 0.11 W.m^{-3}.K^{-1}.

Diagram of the stable ventilating system is presented in Fig. 2. Air, heated in recuperation exchangers (1) was distributed into stable by perforated foil sleeve (2) of diameter 800 mm. The air is withdrawn from stable by ventilators, situated in bottom part (5) of exchangers. Axial ventilators (3) and



2. The stable ventilating system arrangement

1 – the recuperation exchangers from gravitational heat tubes, 2 – inner heated air distribution by perforated foil sleeve, 3 – axial ventilators, 4 – closing holes for the outer air input, 5 – ventilated stable air drawn-off

closing holes (4) enabled to increase intensity of stable ventilation during summer period.

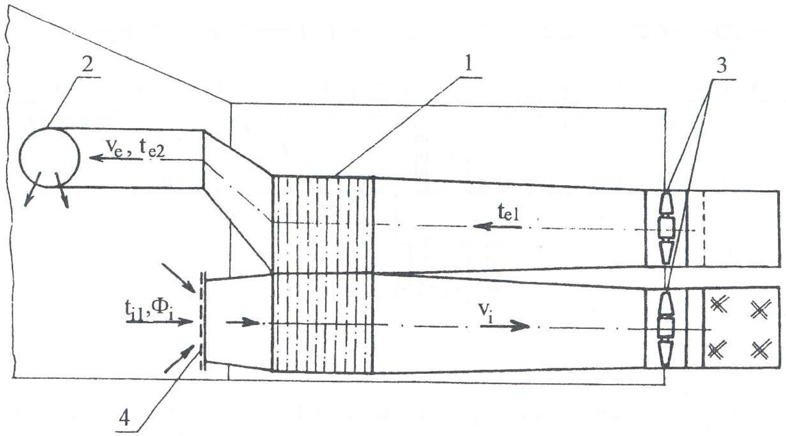
Both recuperation exchangers were assembled together from aluminium lamella gravitational heat tubes (diameter 35 mm) using ammonia, lamella diameter is 62 mm and length 1 960 mm. The exchanger is assembled from 100 heat tubes arranged in 10 rows. In the air-drawn off side, before the heat-exchanging surfaces, textile filters of 3 mm thickness were installed. The purpose of the filters is to protect the heat-exchanging surfaces against pollution by dust, released from dry feedstuffs, small-size feathers and chips particles of bedding.

To assess the exchanger efficiency the following quantities were measured (according to scheme in Fig. 3):

a) temperatures t_{i1}, t_{e1}, t_{e2},
b) drawn-off and coming-in air flowing velocity v_i, v_e,
c) drawn-off air relative humidity φ_{i1},
d) alternating current frequency supplying electromotors of ventilators and regulating their revolutions f.

For temperatures and relative humidity measurements resistive heat sensors PT 100 equipped with voltage output and psychrometers with forced cooling of wet thermometer equipped with voltage output ranging from 0 to 20 mA were used. The air flow velocity was measured by anemometer produced by Ahlborn company.

Regarding the fact, that both temperatures and velocities of the air flow were not constant in the output cross-sections, these cross-sections were di-



3. Scheme of the recuperation exchangers installation and measurement

1 – recuperation exchanger, 2 – heated outdoor air distribution, 3 – axial ventilator, 4 – filter

vided into n equal surfaces of the F_n area, measured individual sections values and analysed the average values for total cross-section. For the measured values recording the measuring central THERM 3280-8M, produced by the Ahlborn comp., equipped with alpha-numeric converter and values recording into the memory were used. The values were recorded within complete measuring in 15min intervals. The ventilation distributing system layout did not enable to measure the air temperature after the evaporating exchanger's part passage t_{i2}.

For unknown temperature t_{i2} the thermal or enthalpy efficiency on the basis of the following consideration was chosen:

a) Dew point temperature t_{ir} calculation for t_{i1}, φ_{i1}, x_{i1}.

b) If the Q_R is calculated according to the equation (2) higher than $Q_{ir} = V_i \,.\, c_{pi} \,.\, \rho_{i1} \,.\, (t_{i1} - t_{ir})$ and if $V_i > V_e$, then the drawn-off air is cooled under the temperature t_{ir} and partial water condensation occurs from the drawn-off air within the heat-changing surface of the exchanger. Enthalpy efficiency is calculated according to the relation (6).

c) If $Q_R \leq Q_{ir}$ and $V_i > V_e$, the fictitious temperature t_{i2} is calculated from the equation:

$$V_i \,.\, \rho_{i1} \,.\, c_{pi} \,.\, (t_{i1} - t_{i2}) = V_e \,.\, \rho_{e1} \,.\, c_{pe} \,.\, (t_{e2} - t_{e1}) \qquad (7)$$

The temperature calculated is to be compared with temperature t_{ir}. If $t_{i2} > t_{ir}$, the water condensation on the heat-changing surface does not occur. The thermal efficiency is then according to the relation (3).

Stable environment parameters measurements to determine the recuperation exchangers efficiency were realized in the first, more difficult half of the breeding period from 27 Febr. to 18 March 1995. Initially, the average weight of chickens was 63 g, final weight was 510 g.

RESULTS AND DISCUSSION

The measurements results presented in Tab. I indicate, that from 27 Febr. to 16 March the tested exchanger operated in condensation regime, and from 17 Febr. to 18 March in heat regime without partial water condensation of

I. Results of measurements and calculated values of recuperation exchanger average efficiency

Date	Calculated values						η_R (–)
	t_{i1} (°C)	t_{e2} (°C)	t_{e1} (°C)	V_e ($m^3.s^{-1}$)	V_i ($m^3.s^{-1}$)	φ_{i1} (%)	
27. 2.	24. 5	22.8	4.5	0.17	0.18	62	0.48
28. 2.	24.2	20.0	2.7	0.17	0.18	68	0.40
1. 3.	25.0	19.2	6.5	0.17	0.18	58	0.36
2. 3.	25.4	16.7	4.6	0.17	0.18	61	0.29
3. 3.	25.2	15.7	5.4	0.17	0.18	64	0.25
4. 3.	25.0	18.6	1.9	0.17	0.18	68	0.36
5. 3.	25.7	14.8	0.6	0.23	0.27	70	0.25
6. 3.	25.3	15.2	2.8	0.23	0.27	68	0.24
7. 3.	26.1	17.6	1.8	0.28	0.40	67	0.23
8. 3.	25.4	13.7	2.1	0.28	0.40	68	0.17
9. 3.	25.5	15.2	2.4	0.28	0.40	61	0.22
10. 3.	24.0	14.7	3.7	0.34	0.52	72	0.18
11. 3.	24.4	14.5	5.2	0.34	0.52	74	0.15
12. 3.	23.9	12.8	4.0	0.47	0.64	76	0.15
13. 3.	23.9	10.4	2.6	0.59	0.79	72	0.14
14. 3.	22.8	6.3	–1.7	0.59	0.79	74	0.13
15. 3.	23.1	8.0	–0.3	0.59	0.79	76	0.13
16. 3.	25.2	11.7	1.4	0.59	0.79	70	0.16
17. 3.	24.1	9.4	3.1	0.75	1.13	72	0.20
18. 3.	24.3	9.7	7.6	0.75	1.13	77	0.07

air origin. Because the volume flow of the drawn-off stable air V_i increases with chickens weight more rapidly than air volume flow V_e, distributed to stable through condensation part of exchanger, it seems to be in correspondence with equation (7) that the heat regime of the exchanger is rather typical for second part of the fattening period.

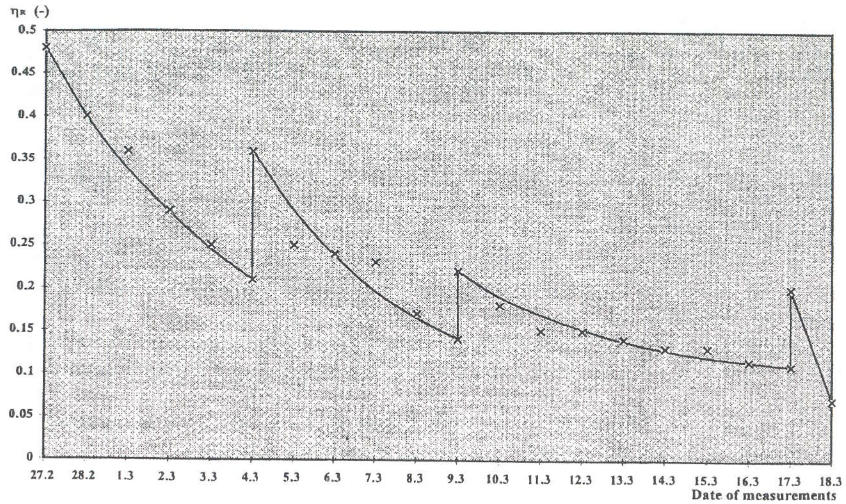
The reached values of the back heat utilization efficiency from ventilated air are significantly lower on average than those stated by Hettwer, Bath (1982) or Kára, Štulc (1989).

The results of our measurements may be well confrontated particularly with results presented by Kára and Štulc (1989). The authors present parameters for exchanger created by gravitational heat tubes equipped with flannel filter in the drawn-off air side. The verification was provided in stable for piglets rearing up to weight 30 kg. The presented results indicated that exchanger operated in range of thermal efficiency in equal-capacity system ($V_i \cdot \rho_i \cdot c_{pi} = V_e \cdot \rho_e \cdot c_{pe}$) and at differences between drawn-off ventilating air t_{i1} and outdoor air temperature t_{e1}, had only reached the values 4.4–6.3 °C. These facts resulted from operative and climate conditions and positively affected the efficiency values ranging from 0.43–0.48. The equal analysis (3, 6) indicates that these values are scarcely reached at deeper differences between indoor and outdoor temperature, increased share of volume flows V_i/V_e and within condensation regime of the exchangers, what resulted in low air over-flow velocity through vapour part of the heat tubes.

The lower efficiency of the tested exchanger is, in our opinion, given also by higher volume flows of removed stable air V_i at higher animals weight. At lower volume flows at beginning of the period the reached efficiency is equal to those presented in the above-mentioned publications.

From graph in Fig. 4 is evident an important effect of the filter on the drawn-off stable air onto efficiency of the secondary heat utilization. Particularly in first six days at equal-capacity ventilation and constant share V_i/V_e considerable efficiency decrease provided by rapid filter pollution at low air velocity is evident. The efficiency decreased at the air flow velocity v_i = 0.51 m.s^{-1} on average by 5.8% during 24 hours. From operative point of view it is necessary to shorten the cleaning interval of filters to three days. At higher velocity of the air flow the efficiency decrease tends to be lower. In the last third of verification at v_i = 2.2 m.s^{-1} the efficiency decrease was almost 1% during 24 hours.

Despite the installed filter, the heat-exchanging surface of the heat tubes vapour part was polluted by small dust particles adhered during water condensation on the surface and generated heat-insulating layer decreased the heat passage coefficient through the heat tube wall.



4. Medium values of the recuperation exchanger efficiency

CONCLUSIONS

The tested system performance without filter is, in fact, impossible. The non-woven textile filter of 3 mm thickness proved to be successful. The exchangers efficiency with polluted filter decreased at low volume flows of the drawn-off ventilating air in first six days of the rearing period by 5.8% during 24 hours. In the first third of the period it is necessary to clean the filter at least each third day of the exchangers operation.

The exchanger with pre-arranged filter operates at low volume flows of the drawn-off ventilating air, i. e. approximately to chicken weight 500 g in the field of the enthalpy efficiency, at higher chickens weight in the field of the thermal efficiency. In practice it is necessary to observe the pollution rate of the heat-exchanging surfaces even behind the pre-arranged filter, particularly at water condensation from removed air.

Acknowledgement

The support of the Czech Grant Agency through the Grant Nr. 504/94/0907 “Study of Base Regulation Components of Power Systems in Agriculture“ is gratefully acknowledged.

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Received for publication on July 20, 1996

ADAMOVSKÝ, R. – HUTLA, P. – BLAŽEK, M. (Česká zemědělská univerzita, Technická fakulta, Praha; Výzkumný ústav zemědělské techniky, Praha-Řepy, Česká republika):

Analýza využití tepla z rekuperačních výměníků v provozních podmínkách stájí.

Scientia Agric. Bohem., *27*, 1996 (4): 303–313.

Cílem práce bylo ověřit a analyzovat možnosti využití výměníků z gravitačních tepelných trubic z hlediska provozních účinností zpětného získávání tepla z větracího vzduchu ve velmi prašném a kvalitativně náročném prostředí stáje pro výkrm kuřecích brojlerů.

Ve stáji pro výkrm 13 000 kuřecích brojlerů byly testovány dva výměníky sestávající ze 100 tepelných trubic umístěných v deseti řadách po deseti kusech. Teplosměnné plochy výparné části tepelných trubic byly chráněny před znečištěním předřazeným filtrem z netkané textilie tloušťky 3 mm. Uspořádání větracího systému stáje a schéma měření rekuperačního výměníku je uvedeno na obr. 2 a 3.

V metodice řešení je podle obr. 1 definována termická účinnost výměníku η_{Rt} (3) pro provozní podmínky, při kterých nedochází k parciální kondenzaci vody z odváděného vzduchu ($x_{i1} = x_{i2}$) a entalpická účinnost výměníku (6) pro provozní podmínky parciální kondenzace vody z odváděného vzduchu ($x_{i1} > x_{i2}$).

Výsledky měření (tab. I, obr. 4) ukázaly, že výměníky s předřazeným filtrem pracují při nízkých objemových tocích odváděného větracího vzduchu, tj. přibližně do hmotnosti kuřat 500 g v oblasti entalpické účinnosti, při vyšší hmotnosti kuřat v oblasti termické účinnosti. V provozu je nutné sledovat stupeň znečištění teplosměnných ploch i za předřazeným filtrem, zejména při kondenzaci vody z odváděného vzduchu. I přes instalovaný filtr se dostaly na teplosměnnou plochu drobné prachové částice, které při kondenzaci vody ulpěly na ploše, a vytvořená tepelná izolační vrstvička snížila součinitel prostupu tepla stěnou tepelné trubice.

Činnost testovaného systému bez filtru je prakticky vyloučena. Filtr z netkané textilie o tloušťce 3 mm se osvědčil. Účinnost výměníku se znečištěným filtrem klesá při nízkých objemových tocích odváděného větracího vzduchu v prvních šesti dnech chovného turnusu o 5,8 % za 24 hodin. V první třetině turnusu je nutné čistit filtr minimálně každé tři dny provozu výměníků. Ve vyšších rychlostech proudění vzduchu má pokles účinnosti klesající tendenci. Při hmotnosti kuřat 450 až 500 g byl pokles účinnosti necelé 1 % za 24 hodin.

stáj; ztráty tepla ventilací; tepelná rovnováha; rekuperační výměník; tepelná trubice; termická účinnost; entalpická účinnost

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