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Fouling Characteristics of Milk-Water System in a Plate Heat Exchanger

R.Balasubramani, A.S.Periasamy Manikandan , K.Kalaivani, R.Baskar

Abstract: ***Fouling is a major problem which affects technical performance and economics of the plate type heat exchanger used for the pasteurization of milk and dairy products. In the present work, experiments were conducted with milk- water system using corrugated plate type heat exchanger (model: M3-FG Alfa Laval) with 13 plates. Experiments were conducted to determine the heat transfer characteristics and fouling resistance by varying the temperature and the flow rate. The enhancement of heat transfer by fouling minimization with the coating of plates with epoxy coating was also studied and reported.***

Keywords: plate heat exchanger, milk, fouling, heat transfer

I. INTRODUCTION

Milk and other dairy products are widely used in many households today. Milk is a popular healthy product which finds its application in most of the food products. The raw milk obtained from the different breeds of cow are collected and taken for the processing of milk in dairy units. The milk obtained cannot be stored as such and it has to be processed so that microorganisms in the milk is destroyed or minimized. Pasteurization is a thermal process where the intent is to lower the concentration of microorganisms in the milk to render it safe to drink. With all the thermal processing of the raw milk, this leads to thermal efficiency degradation of the heat exchangers used to pasteurize the milk due to direct fouling of the heating surface. This study is to find a method to reduce the fouling rate inside parallel plate heat exchangers commonly used in milk pasteurization.

As the requirement of large volumes of milk to be produced each day, large volume production is needed to heat the milk to the temperatures to complete the pasteurization process. The adopted way to pasteurize milk was first used in the dairy industry in 1923, which utilizes the plate type heat exchanger. This type is still used today as the main method to pasteurize milk in a continuous flow process. This design of the plate type heat exchanger incorporates a number of plates, mainly stainless steel, sandwiched together with gaskets that control the flow direction and seal the heating water flow with the product flow. The water and milk flows are then calibrated so that the milk temperature and residence time meet the specification for pasteurization.

Plate Heat Exchangers are very common in dairy industries due to their ease of maintenance and cleaning, their compact designs and their excellent heat transfer coefficient characteristics required for thermal sterilization/pasteurization purposes .However, fouling of plate heat exchanger is a severe problem both technically and economically. It causes significant increases in capital and operating costs. Frequent cleaning of the plant is needed for both microbiological reasons and to restore PHE heat transfer characteristics, i.e. to remove the additional heat resistance of the fouling layer and to reduce the pressure drop in the process plant. Complex Cleaning-In-Place (CIP) techniques have been developed.

Two types of CIP treatments are mainly found in milk processing

1- Two-stage cleaning, using alkali, commonly sodium hydroxide and an acid wash of nitric or phosphoric acid.

2- Single-stage cleaning, using formulated detergents containing wetting and other surface agents as well as chelating compounds.

The plate type design allows for quick cleaning and maintenance which is a necessity when the product forms a film that limits the heat transfer between the water and the product or milk. This film formed from the heated milk will now be referenced as the fouling layer or just fouling. This fouling layer causes the heat exchanger to be taken offline and physically cleaned when the in-situ cleaning procedures fail to maintain cleanliness of the system. The parallel plate type heat exchanger is usually made from 304 stainless steel for corrosion resistance from the product as well as the cleaning steps. The grade of stainless steel might have an effect on the fouling rate of the whole heat exchanger.

Fouling deposit formation on heat exchanger surfaces is a major industrial problem of milk processing plants, which involves frequent cleaning of the installations, thereby resulting in excessive rinsing water and harsh chemicals use. A number of studies have reported the drastic economic costs of fouling. Fouling and the resulting cleaning of the process equipment account for about 80% of the total production costs.

Milk fouling deposit is complex in nature. Deposit is formed by a mixture of inorganic salts (mainly calcium) and proteins (largely whey proteins). The key role played by β-Lg has been recognized in most milk fouling studies. The fouling mechanisms are complicated and involve chemical reactions and heat and mass transfer processes. The deposition is a result of a number of stages occurring at both the bulk volume and the surface as follows:

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* Correspondence Author

R.Balasubramani*, Chemical Engineering department, Kongu Engineering College, Erode, India. Email: rbalasubramani375@gmail.com

A.S.Periasamy Manikandan, Chemical Engineering department, Kongu Engineering College, Erode, India. Email: sriperiasamy@gmail.com

K.Kalaivani, Chemical Engineering department, Kongu Engineering College, Erode, India. Email: kalai_chem@gmail.com

R.Baskar, Food Technology department, Kongu Engineering College, Erode, India. Email: naturebaskar@gmail.com

(i) Unfolding and aggregation of proteins in the bulk;
(ii) Transport of the unfolded and aggregated proteins to the surface;
(iii) Surface reactions resulting in incorporation of protein into the deposit layer;
(iv) Possible reentrainment or removal of deposit towards the bulk.

Michael C. Georgiadis et al (2000)[1] reported the mathematical modeling and simulation work of complex heat exchanger arrangements under milk fouling. The simulation results provide the significant insight into the key factors such as surface temperature, flow rate, no. of plates, composition of milk, presence of micro organisms affecting milk fouling.

Afonso M. Isabel et al (2002) [3] determined heat transfer coefficients of a stirred yogurt and operated with hot and cold water systems to determine the cold water heat transfer coefficients at different flow rates and different no. of plates. It revealed the effect of thermal entry length due to high Prandtl number and to the short length of the plates in the plate heat exchanger.

Bansal et al (2005) [4] done experiments under the title of fouling of heat exchangers by dairy fluids a review. They focused on the mechanism of milk fouling detailing the role of protein denaturation and aggregation reactions as well as mass transfer. They studied the impact of milk composition, operating conditions, heat transfer characteristics, presence of micro organism and location of fouling on heat transfer.

Carla S. Fernandes et al (2005) [5] represented the thermal behavior of stirred yogurt during cooling in plate heat exchangers. The yogurt viscosity was being described by Herschel-Bulkley model. Higher Nusselt numbers than the typical for Newtonian fluids were obtained which was explained by the shear thinning behavior of the studied fluids.

Youcef Mahdi et al (2009) [6] developed a two-dimensional dynamic fouling model for milk fouling in a plate heat exchanger (PHE) was proposed. Emphasis was placed on fouling prediction based on the hydrodynamic and thermodynamic performances of the PHE. The aggregation rate of unfolded protein was found to increase exponentially with increasing wall temperature and was accompanied by a substantial reduction in the heat-transfer coefficient.

Hartmann .D[7] has studied that coatings showed a reduced fouling behavior in comparison with the uncoated stainless steel plates. The electro-polished plates showed also a lower fouling behavior in comparison to the standard stainless steel plates and were almost comparable to the coated plates. The cleaning in place (CIP) time of all coated plates was reduced.

Bansal et al.[8] shows that the investigated the formation of $CaSO_4$ deposit generated by a combination of crystallization and particulate fouling.

Balasubramanian.s et al.[9] studied the effect of PHE surface modification on fouling. The Lectrofluor 641 coated plates exhibited good adhesion qualities with the SS-316 substrate and could minimize the incidence of fouling by 94% to 95% when compared to the control, whereas the Ni-P-PTFE coated plates reduced fouling by 86% to 87.5% but showed signs of discoloration.

Müller-Steinhagen et al. [10] investigated the influence of SiF4 + ion implanted stainless steel, which significantly reduces $CaSO_4$ scale formation during pool boiling.

Kananeh et al. 2009 [11] studied Antifouling coatings based on nanocomposites have been used to decrease fouling on plate and frame heat exchangers used in a food processing plant The low-energy surfaces led to a hydrophobic and an oleophobic effect. In the heating section of a pasteurizer, four different coated plates were equipped in order to study fouling. The pasteurizer was operated with a 10 % whey protein solution, which was heated up to 85 ° C. The CIP time reduction was observed for all coatings: PTFE coated plates down by 90%; nano-composites coated plates down by 70%; electro-polished plates down by 36%.

Premathilaka et al.[12] have studied the fouling behavior of whey protein solutions on modified stainless steel surfaces coated with diamond-like carbon and titaniumnitride.

Boxler C et al.[13] shown the fFouling of milk components on DLC coated surfaces at pasteurization and UHT temperatures.

Murugesan M.P. and Balasubramanian R [14] has studied the effect of mass flow rate and heat transfer characteristics of a corrugated plate heat exchanger for increase of mass flow rate with subsequent increase in the flow velocity. Its providing corrugated (or) embossed patterns to impart high turbulence to the fluids which result in high heat transfer coefficient.

II. MATERIALS AND METHODS

2.1 Experimental Procedure:

The schematic and photographic view of the experimental setup given in Fig:1 and Fig.2.

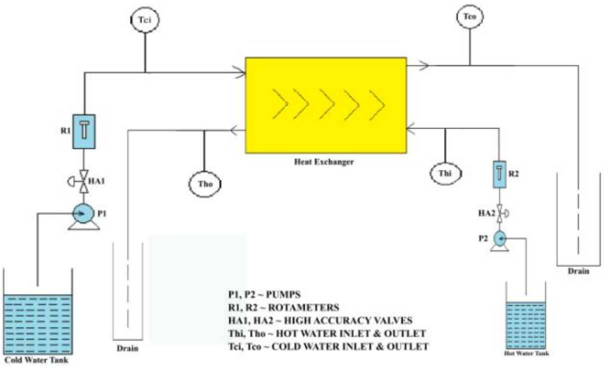

Fig -1: Schematic diagram of experimental setup

Fig -2: Photographic view of experimental setup

The experiments were conducted using corrugated plate type heat exchanger (model: M3-FG Alfa Laval) with 13 plates and the design specifications of the PHE are provided in Table 1. Experiments were conducted to determine the heat transfer characteristics and fouling resistance by varying the temperature and the flow rate.

Table1: Design specifications of the plate type heat exchanger

Length of Plate	405 mm
Height of Plate	480 mm
Width of Plate	180 mm
Gap between two plates	1 mm
Number to plates	13
Number of hot fluid chambers	6
Number of cold fluid chambers	6
Plate material	Alloy 316
Plate thickness	0.5mm
Heat transfer area	0.4 m^2

The experimental set up consists of two containers for storing hot and cold fluid. For heating the hot water, there is a heater which is coupled with a thermostat fixed in the hot fluid container. We can set a temperature in the thermostat, if the fluid reaches that temperature the heater switched OFF. If the temperature lowers, heater will automatically switch ON. Pumps were used for pumping hot and cold fluid. Separate pipelines were connected to pump the hot and cold fluid. These pipelines were fit with gate valves to control and manipulate the flow rate of the fluids. The test fluid inlet pipe is connected to the bottom of the corrugated plate type heat exchanger and the outlet is taken from another end top of the heat exchanger.

Thermocouples were inserted into the pipe to measure the inlet and the outlet temperatures for both fluids. The rotameters are used to measure the flow rate of hot and cold fluids.

Initially the equipment is operated under suitable operating conditions for a water-water system to determine the heat transfer characteristics of hot fluid and cold fluid at different temperature and flowrates. Experiments are conducted for different temperatures and flow rates to determine the characteristics changing with the Reynolds number and Prandtl number. The main issue for conducting experiments is maintaining steady state conditions for each measurement. Temperature, flow rate and pressure drop values have to be read in steady state conditions. Thus, firstly, the heated water and the cold water are sent to the heat exchanger with the help of pumps. After regulating the flows and reaching stable temperatures and flow rates, experiments are started. Temperature values are noted from the digital temperature indicator and the outlet flowrate and velocity for both fluids have been noted.

The experiment is conducted with raw milk as the hot fluid and water as the cold fluid. The milk is heated to pasteurization temperature of 65°C and the heat transfer characteristics are determined with different flow rates. The plates are coated with epoxy coating and the same experiment is done for the same flow rates and conditions. The heat transfer coefficient with and without epoxy coatings are determined and compared. The effect of fouling resistance with respect to heat transfer characteristics are also determined.

III. RESULTS AND DISCUSION

FOR WATER- WATER SYSTEM:

The variation of overall heat transfer coefficient and individual heat transfer coefficient of hot and cold fluid with respect to the Hot inlet temperature is given in Fig:3 . From the graph, it is evident that the Overall heat transfer coefficient and Hot fluid heat transfer coefficient increases with hot fluid inlet temperature. The change in Cold fluid heat transfer coefficient with respect to hot fluid inlet temperature remains constant.

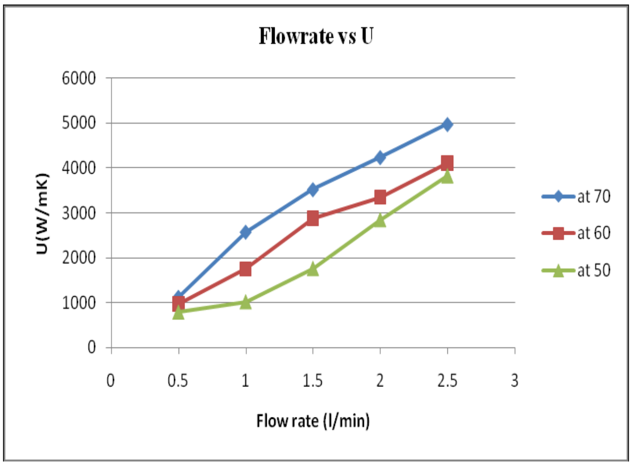

Fig -3: Effect of overall heat transfer coefficient for different flow rates for water-water system

RAW MILK

The variation of overall heat transfer coefficient and individual heat transfer coefficient of hot and cold fluid with respect to the Hot inlet temperature is given by the graph in Fig:4. From the graph, it is evident that the Overall heat transfer coefficient and Hot fluid heat transfer coefficient increases with hot fluid inlet temperature. The change in Cold fluid heat transfer coefficient with respect to hot fluid inlet temperature remains constant. The variation of friction factor with respect to the Reynolds Number is given by the graph .From the graph; it is evident that the amount of friction factor gets reduced whenever the Reynolds number gets increased**.**

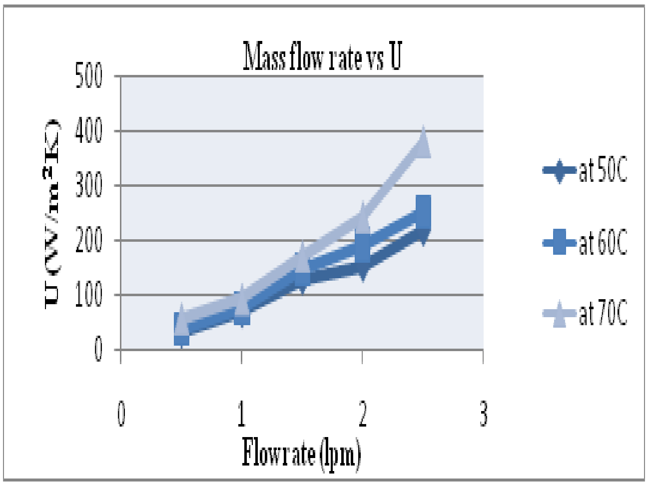

Fig- 4: Effect of overall heat transfer coefficient at different flow rates for raw milk-water system

STANDARDIZED MILK

The variation of overall heat transfer coefficient and individual heat transfer coefficient of hot and cold fluid with respect to the Hot inlet temperature is given in Fig.5.From the graph, it is evident that the Overall heat transfer coefficient and Hot fluid heat transfer coefficient increases with hot fluid inlet temperature. The change in Cold fluid heat transfer coefficient with respect to hot fluid inlet temperature remains constant.

The variation of friction factor with respect to the Reynolds Number is given by the graph and respectively. From the graph, it is evident that the amount of friction factor gets reduced whenever the Reynolds number gets increased. This will vary for the other two types of milk.

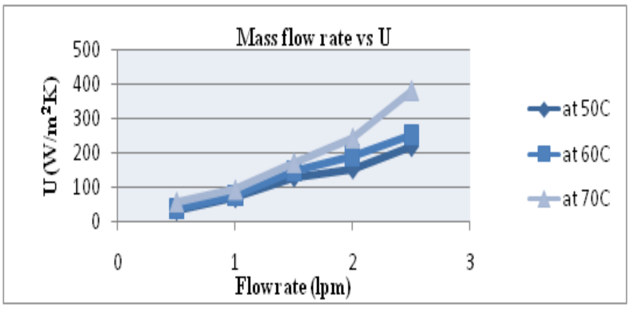

Fig-5: Effect of overall heat transfer coefficient at different flowrates for standardized milk-water system

FOULING STUDIES OF STANDARDIZED MILK

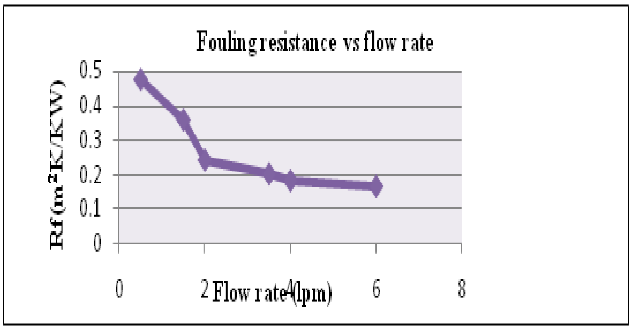

Fig-6: Effect of fouling resistance at different flowrates for standardized milk-water system

Figure 6 represents the effect of flow rate on fouling resistance for standardized milk and water system. Fouling resistances were calculated using the clean U-values evaluated during the preliminary tests and under identical flow rate combinations as those used to calculate the initial clean heat transfer coefficients.
Flow rates ranged from 1 l/min to 6 l/min in steps of 2.5 l/min. At low flow rates (0.5-2.5l/min) an asymptotic curve was observed which included a short induction period. However at flow rates above 4.5 l/min, an extended induction period occurs followed by a linear increase with no asymptote reached. The effect of flow rate on fouling resistance was to significantly affect the induction period, the slope of the linear period of the graphs and the asymptotic fouling resistance.

Effect of fouling resistance in clean and dirt conditions

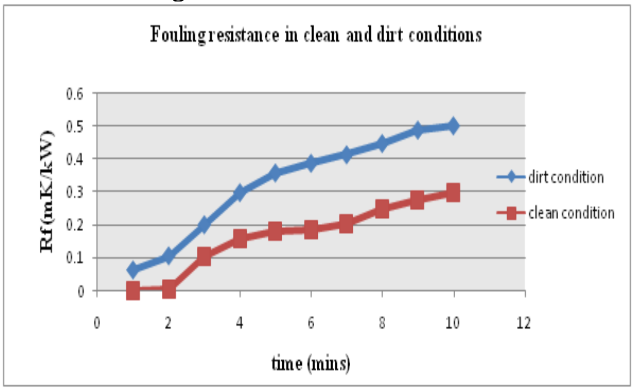

Fig- 7: Effect of fouling resistance in clean and dirt conditions

Figure 7 represents the effect of flow rate on fouling resistance for standardized milk and water system in clean and dirt conditions. Fouling resistances were calculated using the clean U-values evaluated during the preliminary tests and under identical flow rate combinations as those used to calculate the initial clean heat transfer coefficients.
Flow rates ranged from 1 l/min to 6 l/min in steps of 2.5 l/min. At low flow rates (0.5-2.5l/min) an asymptotic curve was observed which included a short induction period. This graph shows the change in fouling resistance when equipment is cleaned properly using correct cleaning procedure. Increase in fouling resistance is due to pressure drop variations. The overall heat transfer coefficient gets affected by fouling. This will reduce the clean in place (CIP) conditions.

Effect of pressure drop in the system

The graph given in Fig: 8 shows the relationship between pressure drop and Reynolds number. Pressure drop is usually high at maximum flowrate. But in this experiment the chance of turbulence flow is in fewer conditions. Even though the pressure drop between inlet and outlet ports is measured and calculated using the fluid outlet flowrate and velocity. Initially the pressure drop increases gradually up to a certain level, at higher Reynolds number and it is maintained constant when the milk undergoes higher temperatures exceeding 100°C.

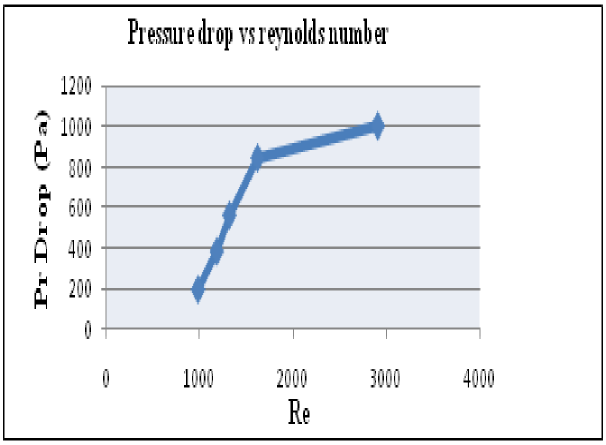

Fig-8: Effect of pressure drop at various Reynolds number

IV. CONCLUSIONS

This research work is focused on heat transfer analysis of corrugated PHE and also to investigate experimentally the performance of corrugated PHE with regard to convective heat transfer coefficient, heat exchanger effectiveness and to test the effect of varying mass flow rate of working fluid on effectiveness. Following are the findings of this experimental investigation:

Convective heat transfer coefficient increases with Reynolds number and mass flow rate for both parallel and counter flow arrangement. This is due to the fact that flow becomes more turbulent and cause for turbulence can be attributed to plate geometry i.e., corrugations as well as high flow velocity.

Effectiveness of heat exchanger decreases with increase in mass flow rate of hot fluid. Maximum effectiveness for parallel flow arrangement is 0.67 and that of for counter flow arrangement is 0.82.

This experimental investigation on corrugated PHE can be extended with multi-phase working fluids such as oil to water. This work can be further extended for heat transfer analysis of nanofluids.

REFERENCES

1. Michael .C Georgiadis, Sandro Macchieto, (2000) Dynamic modeling and simulation of plate heat exchangers under milk fouling, Chemical Engineering science 55 (200)- 1605-1619.
2. R. K. Shah and D. P. Sekulic, "Fundamentals of Heat exchanger design" (2003)
3. Afonso M. Isabel, Lubos Hes, Joao M. Maia, Luis F. Melo (2002) Heat Transfer and Rheology of stirred yogurt during cooling in plate heat exchangers Journal of Food Engineering 57(2003)179-187.
4. Bansal B. X.D. Chen, (2005) Fouling of heat exchangers by dairy fluids Proceedings to International conference on heat exchangers Vol : RP2 Article 23.
5. Carla S. Fernandes, P. Dias, J. M. Nobrega, Luis F. Melo (2005) Thermal behavior of stirred yogurt during cooling in plate heat exchangers journal of Food Engineering 76(2006) 433-439.
6. Youcef Mahdi, Abdelkader MouHeb, Lounes Quker (2009) A dynamic modeling of milk fouling in plate heat exchangers, Applied mathematical modeling, 33 948-662.
7. Hartmann .D (2009) Application of antifouling surfaces in plate heat exchanger Proceedings of International conference on heat exchanger VII Article 32
8. Bansal, B., Chen, X., 2006. A critical review of milk fouling in heat exchangers. Compr. Rev. Food Sci. F. 5, 27–33.
9. Balasubramanian, S., Puri, V.M., 2009. Reduction of milk fouling in a plate heat exchanger system using food-grade surface coating. Trans. ASABE 52 (5), 1603–1610.
10. Beuf, M., Rizzo, G., Leuliet, J.C., Müller-Steinhagen, H., Yiantsios, S., Karabelas, A., Benezech, T., 2003. Fouling and cleaning of modified stainless steel plate heat exchangers processing milk products. In: Watkinson, A.P., Müller-Steinhagen, H., Malayeri, M.R. (Eds.), Proceedings of International Conference Heat Exchanger Fouling and Cleaning. Santa Fé, USA, RP1, pp. 99–106.
11. Kananeh, A.B., Scharnbeck, E., Kück, U.D., Räbiger, N., 2010. Reduction of milk fouling inside gasketed plate heat exchanger using nano-coatings. Food Bioprod. Process. 8 (4), 349–356.
12. Premathilaka, S., Hyland, M., Chen, X., Bansal, B., 2006. A Study of the effects of surface chemistry on the initial deposition mechanisms of dairy fouling. Food Bioprod. Process. 84 (4), 265–273.
13. Boxler, C., et al., Fouling of milk components on DLC coated surfaces at pasteurization and UHT temperatures. Food Bioprod Process (2012), http://dx.doi.org/10.1016/j.fbp.2012.11.012
14. Murugesan M.P. and Balasubramanian R., The Effect of Mass Flow Rate on the Enhanced Heat Transfer Characteristics in a Corrugated Plate Type Heat Exchanger, Research Journal of Engineering Sciences, 1(6), 22-26 (2012)

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