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MULTIPLE ORIFICE BUBBLE GENERATION IN GAS-SOLID FLUIDIZED BEDS: THE ACTIVATION REGION APPROACH

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Multiple orifice bubble generation in gas-solid fluidized beds: the activation region approach

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ABSTRACT

This work addresses the bubble generation mechanism at multi-orifice distributors in gas-solid fluidized beds (FB). Different measurements techniques such as high speed video camera and Kistler pressure transducers were applied to obtain information from both local, and global bed dynamics. Pressure fluctuation time series are used for dynamic diagnosis of the 2-D facility used during the study. The bed was operated with different distributor plates at several bubbling conditions leading to different bubble flow patterns characterized by digital image analysis of both the dense and the bubble phases.

In order to explain the bubble pattern developed within the bed and the measured bubble dynamics, a phenomenological discrete bubble model is used. This model proposes an activation region (AR) mechanism for multi-orifice bubble generation. The underlying hypothesis is that the bubble formation can be placed in a region above the distributor plate where the initial bubble size is the result of the dynamical interaction of neighbour orifices.

From the analysis of the experimental results, it is observed how for two different uniform gas distribution across the distributor plate, bubble dynamics interactions play the main role as the driver of the resulting bubble flow pattern developed within the bed. Moreover, when the activation region hypothesis is used as a bubble generation mechanism in a phenomenological discrete bubble model, it is seen that the proposed activation region mechanism, explains the observed bubble generation phenomena at multi-orifice distributors, and leads to a substantial decrease of the computational cost to simulate bubbling FB dynamics.

INTRODUCTION

The distributors design becomes critical to ensure the desired overall performance of a FB system. Thus, the gas distributor in a FB is intended: to induce an uniform and stable fluidization across the entire bed cross section; to prevent non fluidized regions on the grid; to operate for long periods without plugging or breaking, minimize the "rain" of solids into the plenum beneath the grid; to minimize attrition of the bed material, and to support the weight of the bed material during start up and shut down. Despite of recent studies allow grid design based on scientific principles (Werther and Hartge (1)), further research effort is needed to address the understanding and prediction of the mixing pattern above the distributor. It is well known that for multi-orifice distributors, the mixing at the distributor region is mainly influenced by the nature and length of jets, which are directly related with the separation and the diameter of the orifices as well as with the properties of the FB particles and the flow-rate of the gas (Rees et al.(2)).The interaction between these jets have a direct influence in the bubble generation and consequently, on the final global behaviour of the FB.

The information reported in literature regarding the multi-orifice bubbling formation in gas-solid FBs is rather scarce (Leung, (3)). However recent studies (Rees et al. (2),) report evidences about a region close the distributor plate which used to exhibits permanent jets. According to that, in order to explain the bubble pattern developed within the bed and the measured bubble dynamics it is proposed an AR mechanism for multi-orifice bubble generation. The underlying hypothesis is that the bubble formation can be placed in a region above the distributor plate where the initial bubble size is the result of the dynamical interaction of neighbour orifices (Briongos et al. (4)). Thus, it is shown how for two uniform multi-orifice distributor having the same pressure drop across the distributor plate and different grid configuration, the bubble dynamics interactions play the main role as the driver of the resulting bubble flow pattern developed within the bed.

EXPERIMENTAL SETUP

The experiments were carried out in a 2-D cold FB 50 cm wide *w*, 200 cm high *h* and 0.5 cm thick *t.* The front wall was made of glass and the back panel was made of aluminium and covered by a black card to get a higher contrast in the images. Two 650 watts spotlights were used in order to have a uniform illumination of the bed. The bed was filled with white Geldart-B glass particles, Geldart (5) , 2500 kg/m^3 density ρ_p , and 600-800mm diameter d_p, previously sieved. Two distributors type were used in the experiments, with 24 holes of 1mm diameter and an opening ratio of 0.75%, Fig.1, for each one, five different ratios between the superficial gas velocity, U, and the minimum fluidization velocity, Umf (0.34 m/s), (U/U_{mf} = 1.5, 1.75, 2, 2.25, 2.5) and three different fixed bed height, (h_1 = 15, 30, 45cm) were used. Therefore, in this work, a total of 30 cases were studied. For each case, 3271 images were acquired using a high speed video camera, at 125 frames per second. The non intrusive techniques DIA-PIV (Digital Image Analysis – Particle Image Velocimetry), were used to analyse the getting information. With these techniques, not only the phases are clearly identified (dense phase and bubble phase), but also an images superposition reports the time that the points are occupied by bubbles or solids, and the mean dense phase velocity was calculated (Sanchez-Delgado et al. (6)). Three piezoelectric pressure sensors, Kistler type 7261 and three Kistler amplifier type 5011 connected to the probes were used to get information about pressure fluctuation. The sample frequency was of 200 Hz (Villa et al. (7)) The distributor Type I and II have an homogeneous distribution of holes along the distributor keeping constant the ratio between open area and total area, therefore they share the same characteristic curve pressure drop through the distributor vs. superficial gas velocity $\Delta P = 30000U^2$, Fig 1. shows the scheme the distributor types.

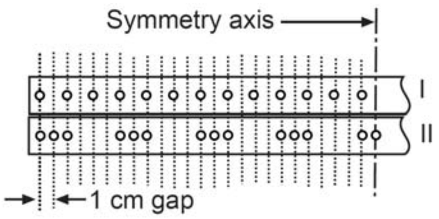
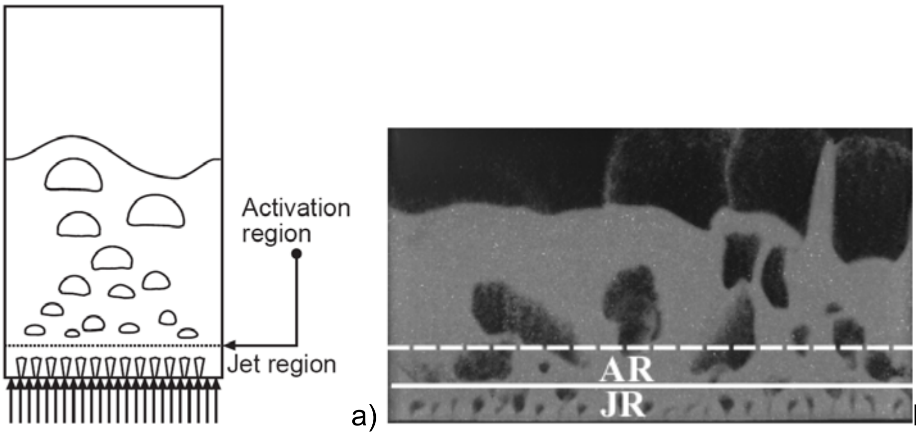


Fig 1: Scheme of the distributors design

THE ACTIVATION REGION MECHANISM

Regarding multi-orifice bubble generation, studies on gas-liquid systems reveal that the orifices active in one part of the distributor enhanced the bubble generation within their nearest distributor region (Ruzicka et al. (8)) (Xiao and Tan (9)), making the orifices which belong to other distributor regions passive for bubble formation. As stated above, more recently, Rees et al. (2), working with gas-solid FBs, has reported that in the case of multiple-orifice distributors and for $U/U_{mf} > 1$, the region close the distributor plate exhibits permanent jets, where the upper parts of the jets merged forming a central dilute core and the bubble detachment takes place in a closer region above the distributor. That information serves to propose the AR mechanism. This assumes that the initial bubble size is the result of the dynamical interaction of neighbour orifices



a) b)

Fig. 2: a) AR scheme b) 2-D FB operating at bubbling regime. The solid line accounts for the limit of the orifice interaction region, JR (jet region), the active regions i.e bubbles, AR, will appear above the JR

As a consequence of the AR hypothesis, the multi-orifice plate is seen as a discrete source of information where the bubbles are the dynamical message to be transmitted, Fig. 2. Thus, in agreement with the results reported by Rees et al. (2), the Fig. 2b) shows a picture of an experimental 2-D FB system operating at bubbling conditions with a multi-orifice distributor, which serves to illustrate the idea behind the AR mechanism.

EXPERIMENTAL EVIDENCES OF THE ACTIVATION REGION

In order to show that bubble dynamics interactions play the main role as the driver of the resulting bubble flow pattern developed within the bed, and consequently, that the overall bed dynamics under those conditions, apparently, does not depend on single orifice bubble generation, it is shown how two uniform multi-orifice distributor having the same pressure drop and different grid configuration, lead to the same dynamical bubble pattern when the beds are operated at the same fluidization conditions. According to the proposed hypothesis, both distributors (I, II) should be characterized by the same AR, which give rise through bubble interaction to the final dynamical bubble pattern characterizing bed dynamics.

Bubble pattern and dense phase velocity for different distributors

First, the bubble pattern within FB is obtained using the DIA technique, once the images were acquired, a threshold transformation was applied in the images, getting pixels of value 1 for point occupied by bubbles and pixels of value 0 for points occupied by dense phase, with the superposition of these transformed images, a time averaged maps were generated showing the time that the point (i,j) is occupied by bubbles or by dense phase (Sanchez-Delgado et al. (6)). Fig. 3, shows the time averaged results for images superposition in two different cases. In order to compare the internal structure of the FB with these two different distributors, Fig. 4 shows two cuts at different heights above the distributor

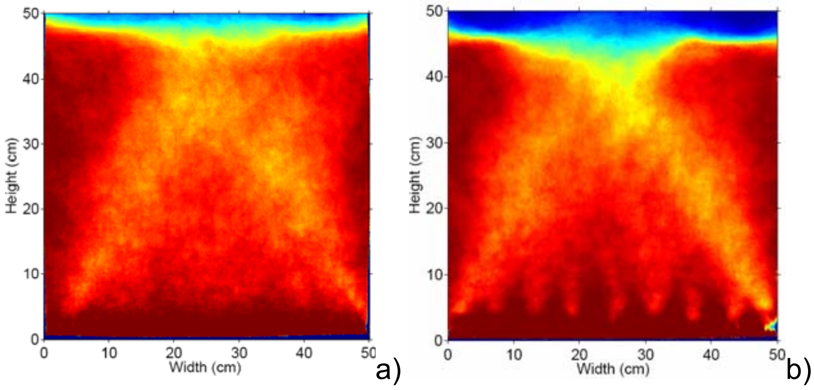


Fig. 3: a)Type I, h1 = 45 cm, U/U_{mf}=1.5, b) Type II, h1 = 45 cm,U/U_{mf} = 2.25

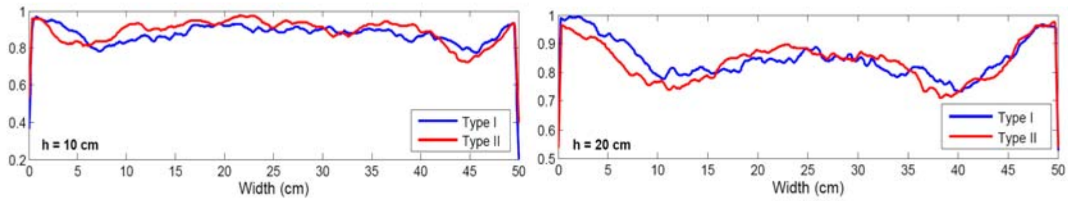


Fig. 4: Proportion of time that a point has been occupied by solids at different height above distributor, h_1 = 45 cm, U/U_{mf} = 2.25

There are no significative differences in the bubble pattern of the FBs. Fig.5, shows the analysis in the region just above the distributors in Fig.3, showing the boundary that divides the "jetting region" from the "bubbling region". From the Fig.5 it can be seen the differences between the orifice interaction of the two distributors.

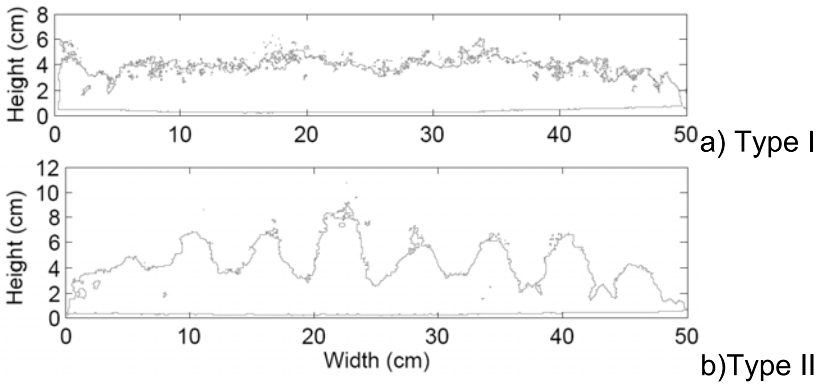


Fig. 5: Contour plot close the distributors, h_1 = 45 cm, U/U_{mf} = 2.25

In Fig. 6 the bed aspect ratio has decreased (h_1=15 cm) and two relations between U and U_{mf} have been analyzed. The same analysis of Fig. 4, at different heights of the fluidized, was applied in images of Fig. 6, corroborating the no influence of the orifice distribution along the distributor in the overall bubble pattern of the FB beyond the AR. Moreover, in agreement with Rees et al. (2), Fig. 6 shows the effect of the flow rate in the jet formation, as the flow rate increases the AR is located closer to the distributor.

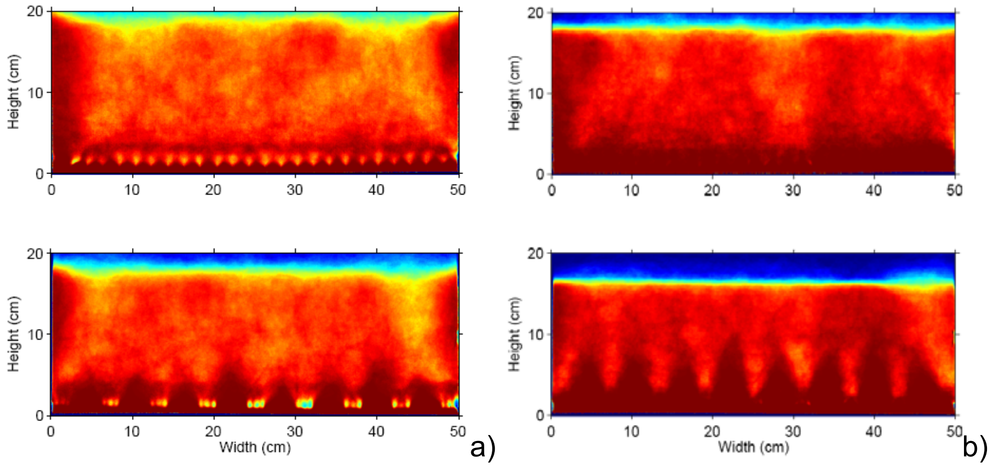


Fig. 6: a-1) Type I, h_1=15 cm, U/U_{mf} = 2.25, a-2) Type II, h_1=15 cm, U/U_{mf} = 2.25, b-1) Type I, h_1=15 cm, U/U_{mf} = 1.75, b-2) Type II, h_1 = 15 cm, U/U_{mf} = 1.75

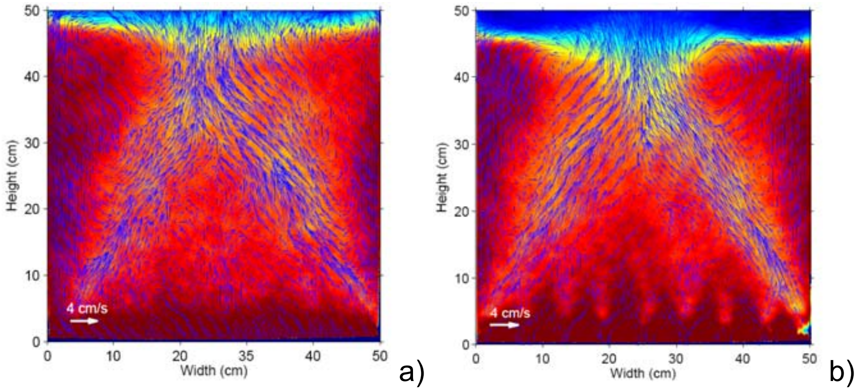


Fig. 7: Time averaged dense phase velocity results and bubble pattern. a) Type I, h = 45 cm and U/U_{mf} = 2.25 b) Type II, h = 45 cm and U/U_{mf} = 2.25

Fig. 7 shows the time-averaged dense phase velocity results for the same cases presented in Fig. 3, providing qualitative information about the distributor influence in the dense phase behaviour. It is clear the similarity between both cases, which have an upwards moving dense phase in the central section of the bed, and two downward moving dense phases on the walls of the FBs. Therefore, apparently they exhibit the same internal flow structure.

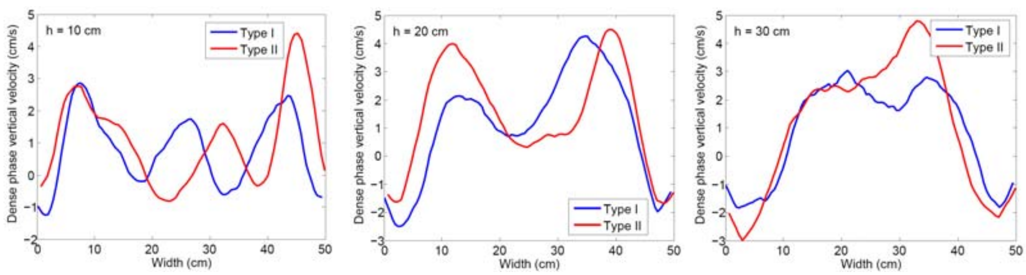


Fig.8: Vertical dense phase velocity at different heights, h_1=45 cm U/U_{mf} = 2.25

Moreover, it is worth to point out that the vertical velocity values for both cases at different heights above the air distributor are very similar for both distributors. Fig. 8

Dynamic analysis

Complementarily to the previous digital image analysis, the time series collected by means of the Kistler pressure transducers are used to compare the overall FB dynamics characterizing two beds operating with different distributor plates. Thus, frequency domain is applied over the measured pressure fluctuation signal for dynamical comparison.

Frequency Domain Analysis

The frequency domain representation of the signal can be described by the estimation of its power spectral density, PSD. Here, the well known Welch's averaged periodogram method is used to compute the PSD (Johnsson et al. (10)).

Dynamical comparison

The normalized frequency spectra of the measured pressure fluctuation time series are shown on Figure 9.

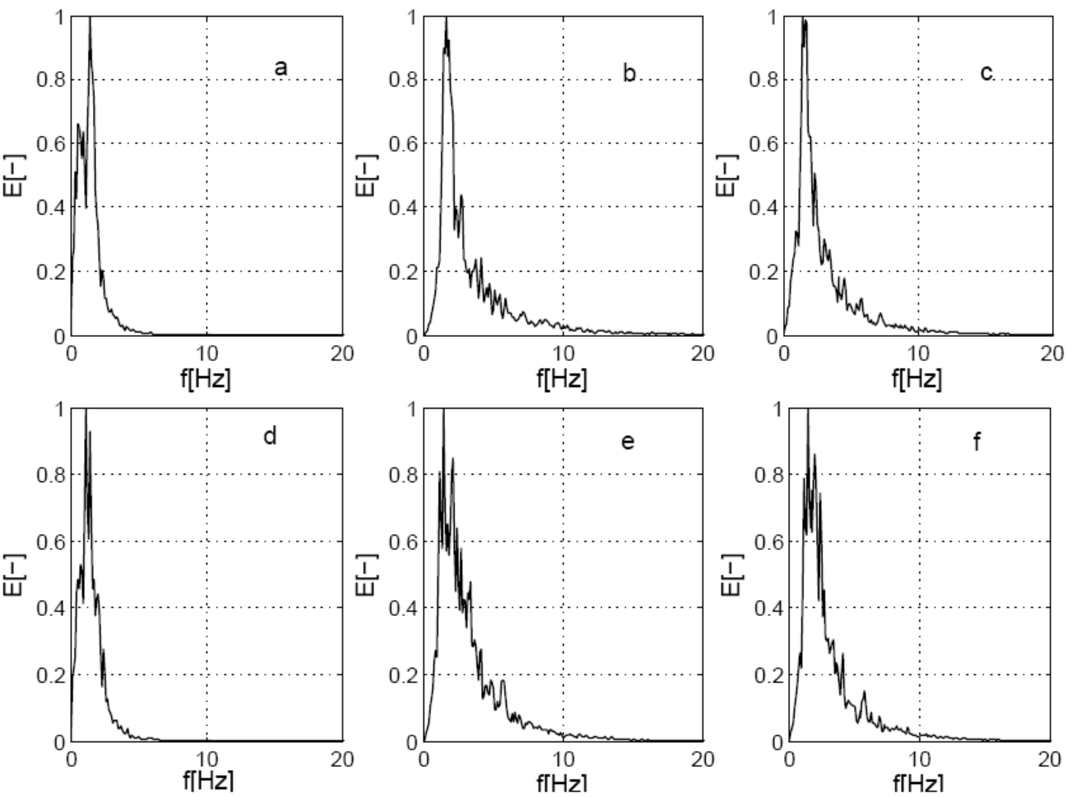


Fig. 9: Normalized power spectral density estimation for distributor I (a,b,c) and II (d,e,f) from pressure fluctuation time series collected respectively at h = 0 m, 0.2 m, 0.45 m (U/U_{mf}=2.25).

The characteristic frequencies of the 2D bed operating with either distributor plate configurations (I, II), are very similar. Only slightly differences can be observed in the spectra estimated from the signals measured in the middle and bottom bed regions, which seem to be more influenced by the jetting region. In contrast the top bed dynamics exhibit a remarkable matching for both situations. According to that the dynamical regime developed in both systems exhibit a similar frequency structure characteristic of multiple bubbling regime The multiple bubble regime, is a well bubbling FB with a uniform bubble distribution and, with the bubbles evenly distributed over the cross-section of the bed. Moreover, ΔP is of the same order as the pressure drop across the bed, which results in bubbles that are much smaller than the wide bed dimension (0.7 m). (Johnsson et al. (10)).

THE ACTIVATION REGION MODEL

The AR model is a discrete phenomenological approach where bubbles are modeled as spherical-cap discrete elements that rise through the emulsion phase that is considered as a continuum. Furthermore, the bubbles are dynamically coupled to its closest leading neighbor through a wake acceleration force that accounts for the bubble trailing interaction. The bubble coalescence is modeled including a shrinking/growing mechanism that gradually increases or decreases the size of the coalescing bubble pair. Moreover, bubble formation at the distributor plate has been modeled according to an AR mechanism to provide different bubble patterns. As an example of the reliability of the AR approach, Figure 10 shows the frequency domain comparison between simulated and experimental pressure fluctuation time series collected from a bench-scale combustor, having a Tuyere type distributor plate, operating at ambient temperature at multiple bubble regime.

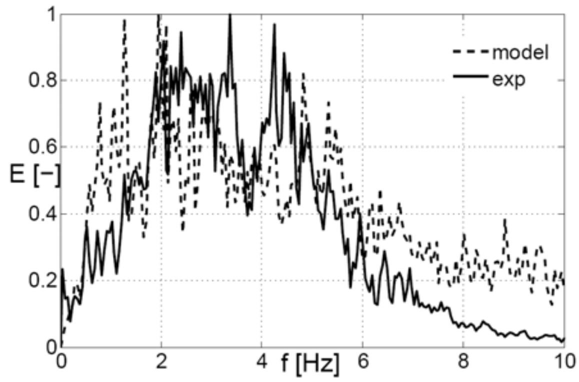


Fig. 10: Normalized power spectral density estimation for simulated and experimental pressure fluctuation time series collected from a bench-scale combustor operating at U/U_{mf} =2.1

CONCLUSIONS

It has been proved how two uniform multi-orifice distributor having the same pressure drop and different grid configuration, lead to the same dynamical bubble pattern and global bed behaviour (above the activation region) when the beds are operated at the same fluidization conditions. Consequently, it is concluded that the bubble dynamics interactions play the main role as the driver of the resulting bed dynamics developed within the bed, and therefore, the overall bed dynamics for uniform gas distribution conditions does not depends on grid configuration for the fluidization condition covered.

NOTATION

AR, JR : Activation and jet region [-]
$d_{p:}$ Particle diameter [m]
Δp: Pressure drop through the distributor [-]
h: FB height, [cm]
h_1: Fixed bed height [cm]
(i,j) Horizontal and vertical coordinates for a pixel, [cm]

U: Superficial gas velocity [m/s]
U_{mf}: Minimum fluidization velocity, [m/s]
w: FB width, [cm]
t: FB thickness, [cm]

Greek letters
ρ_L: Liquid density [kg/m^3]
ρ_p: Particle density [kg/m^3]

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