Hydrodynamic and Mass Transfer Performance of a Hybrid Pulsed Column for Solvent Extraction

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Abstract *– A novel hybrid internal is designed by adding packing on standard sieve plate as a possible way to intensify the mass transfer performance of pulsed sieve plate column. Its hydrodynamic and mass transfer performance is tested under pilot plant conditions and compared with standard pulsed sieve plate column. Results show that holdup of hybrid internal is higher than that of standard sieve plate by around 50%. Sauter mean diameter d_{32} of hybrid internal is smaller than that of standard sieve plate by around 40%. These two factors result in higher specific mass transfer area for hybrid internal. Axial dispersion coefficients of hybrid internal is lower than that of standard sieve plate by around 50%, indicating less decrease of mass transfer efficiency from axial dispersion for hybrid internal. Mass transfer experiments show that H_{oxp} of hybrid internal is lower than that of standard sieve plate by around 40%, indicating better mass transfer efficiency when packing added, which can be explained by the previous factors.*

Keywords: Solvent extraction column, Hybrid internal, Hydrodynamics, Axial dispersion, Mass transfer

1.Introduction

Liquid-liquid extraction is an important separation process. Solvent extraction columns have been used for a range of applications in chemical, petroleum, nuclear, hydrometallurgical industries and other fields for many years[1-3]. Extraction columns have advantages over other devices such as its high volume efficiency, small footprint and environmentally friendly features.

In industrial applications, various types of solvent extraction columns are used including Kuhni column, Karr column, pulsed sieve plate column and so on. Fei et al. [4] summarized these types of extraction columns by different methods of energy input, and the classification is shown in

Table 1. In these columns pulsed sieve plate column is widely used because the inside geometry is simple without moving parts, which makes the maintenance much easier. Also energy can be given by air pulse at a distance so that remote control of the device is possible. In this study, one possible way to improve the mass transfer efficiency of pulsed sieve plate column by adding packing on the plates is investigated, this new type of internal is called hybrid internal.

Table 1: Classification for solvent extraction columns[4].

Energy input	Stage contacting	Continuously contacting
Gravity	Sieve plate column	Spray column
		Packing column
Agitation	Eccentric RDC	RDC
		Kuhni column
Vibration		Karr column
Pulsation		Pulsed disc and doughnut column
		Pulsed sieve plate column

Hydrodynamic parameters including holdup and drop size, are important as they determine the specific interfacial area which effects mass transfer performance. Axial dispersion coefficient is also important because it characterizes the non-

ideal deviation from plug flow, which decreases the mass transfer efficiency. So these three parameters are measured and compared for both types of internals to explain the comparison in mass transfer efficiency, which is measured with height of overall mass transfer unit from steady state mass transfer experiments.

2. Experimental

The novel hybrid internal investigated in this study and the standard sieve plates are shown in Figure 1 for comparison. The sieve plate (Figure 1B) has a standard design with 23% open area and 3 mm diameter holes with a plate thickness of 2 mm. The specific surface area of this packing in hybrid internal is 650 m^2/m^3. The plates are held in place with three steel rods and 48 mm long spacer sleeves (see Figure 1C) to evenly divide the length between each plate to be 50mm, which is also the compartment height. The packing can be placed on the plates with the sleeves crossing three holes to keep its position (see Figure 1A). A photo of the installed hybrid internal is shown in Figure 1D.

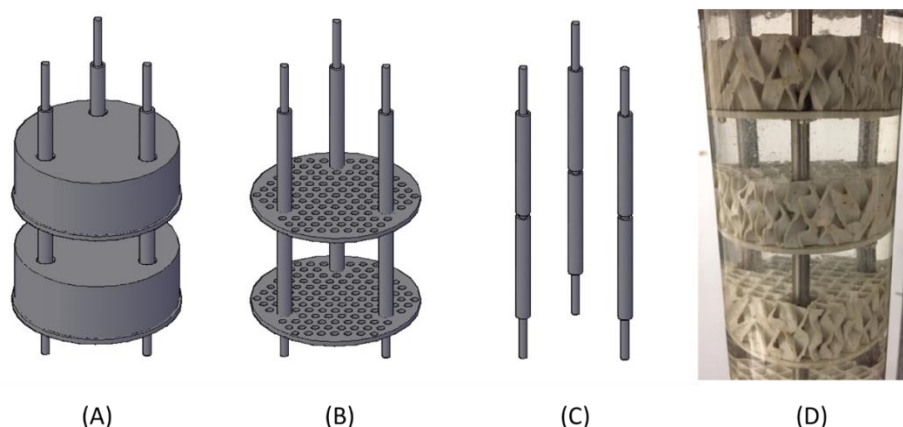(A)   (B)   (C)   (D)

Fig. 1: Schematic diagrams and photograph of internals (A) hybrid internal (B) standard sieve plate (C) tie rods (D) photograph of hybrid internal.

All experiments were performed in a pilot plant column, refer to process flow diagram shown in Fig. 2[5]. This is made up of a 1.0 m long QVF® precision bore glass column with an internal diameter of 72.5 mm. The organic phase outlet is a glass T-piece on top of the column body. The internal diameter of the glass section at the bottom of the column increases to 100 mm with a stainless steel distributor inside. A stainless steel conical adapter then reduces the diameter to 50 mm and is connected to a piston-type pulsing unit. This pulsing unit consists of a motor, a variable speed unit (controls the frequency), a variable eccentric drive head (controls the amplitude), a crank arm and a plunger equipped with a Teflon cylinder and two rubber seals in a stainless steel cylinder. Sinusoidal motion is provided by the plunger to the fluids in the column.
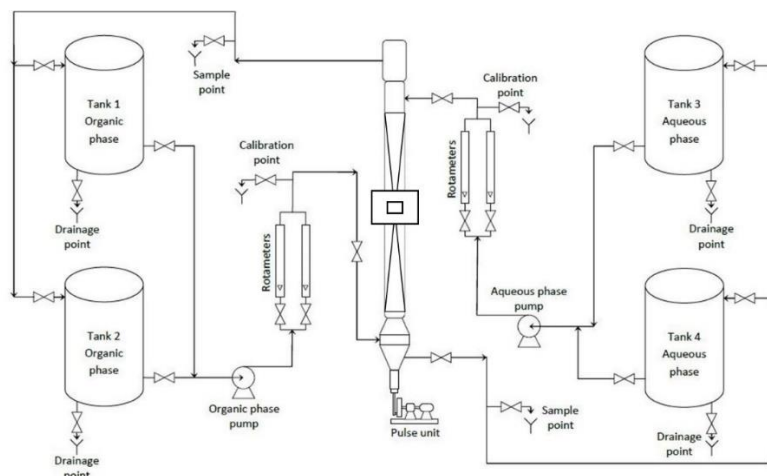
Fig. 2: Experimental pilot plant column process flow diagram.

The organic phase used in this study is 30 vol% TBP (tributyl phosphate), supplied by Myer (Shanghai) in Shellsol 2046®, supplied by Shell Australia. Glacial acetic acid supplied by Thermo Fisher is diluted and used as solute. The aqueous phase used is tap water. The tracer used in axial dispersion experiments is 1 w% Tartrazine yellow (Acid yellow 23) solution, supplied by Sigma Aldrich. The physical properties, including densities, viscosities and interfacial tension were analysed and presented in Table 2.

Table 2: Physical properties of the aqueous and organic phases.

	Aqueous	**Organic**
Density (kg/m^3)	1008	844
Viscosity (Pa·s)	1.06×10^{-3}	2.05×10^{-3}
Interfacial tension(mN/m)	10.1	

3. Results and discussion

3.1. Holdup

Dispersed phase holdup is measured by the volume displacement method[6]. Holdup for hybrid internal is compared with that of standard sieve plate in Fig. 3, in which holdup of both internals are compared under two pulsation conditions while the dispersed phase superficial velocity varies from 6×10^{-4} to 3.5×10^{-3} m/s. With an increase of dispersed phase flow rate, holdup increases accordingly. Under all pulsation conditions, the holdup of the hybrid internal is higher than that of the standard sieve plate. In general, holdup of hybrid internal is higher than that of standard sieve plate by around 50%.
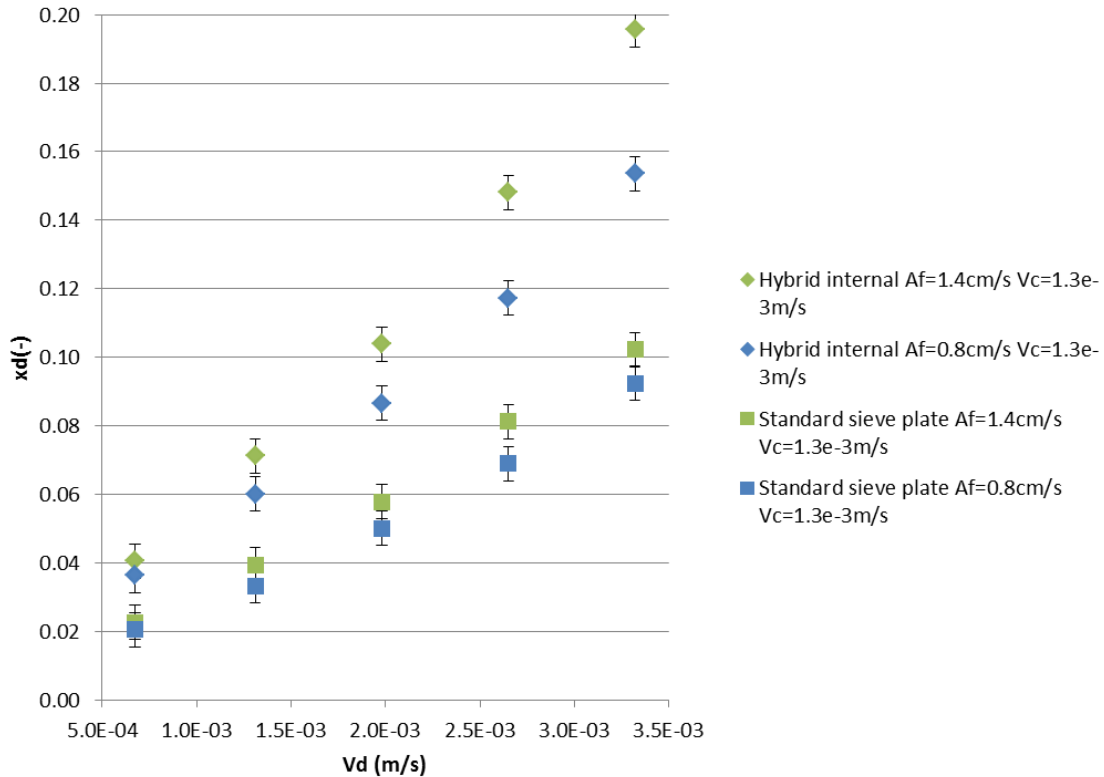

Fig. 3: Holdup (xd) of the hybrid internal compared with standard sieve plate with variation of dispersed phase superficial velocity (V_d).

3.2. Drop Size

Drop size is measured and counted with photography method[7]. Fig. 4 shows experimental d_{32} of hybrid internal compared with that of standard sieve plate under different pulsation intensities and continuous-dispersed phase ratios. Pulsation intensity varies from 0.3 to 2.4 cm/s, while phase ratio varies from 0.5 to 2. Results show that d_{32} for both internals decreases with an increase of pulsation intensity, and it decreases more dramatically when pulsation intensity is low. Results also show that both phase flow rates, indicated by continuous-dispersed phase ratio in this case, have little effect on drop size. This shows that the energy input is the dominant factor in determining drop size. In all cases considered in this study, drop size obtained with the hybrid internals is smaller than that of standard sieve plate. This fact, together with the higher holdup of hybrid internal, gives larger mass transfer area and will contribute to mass transfer efficiency for this internal.
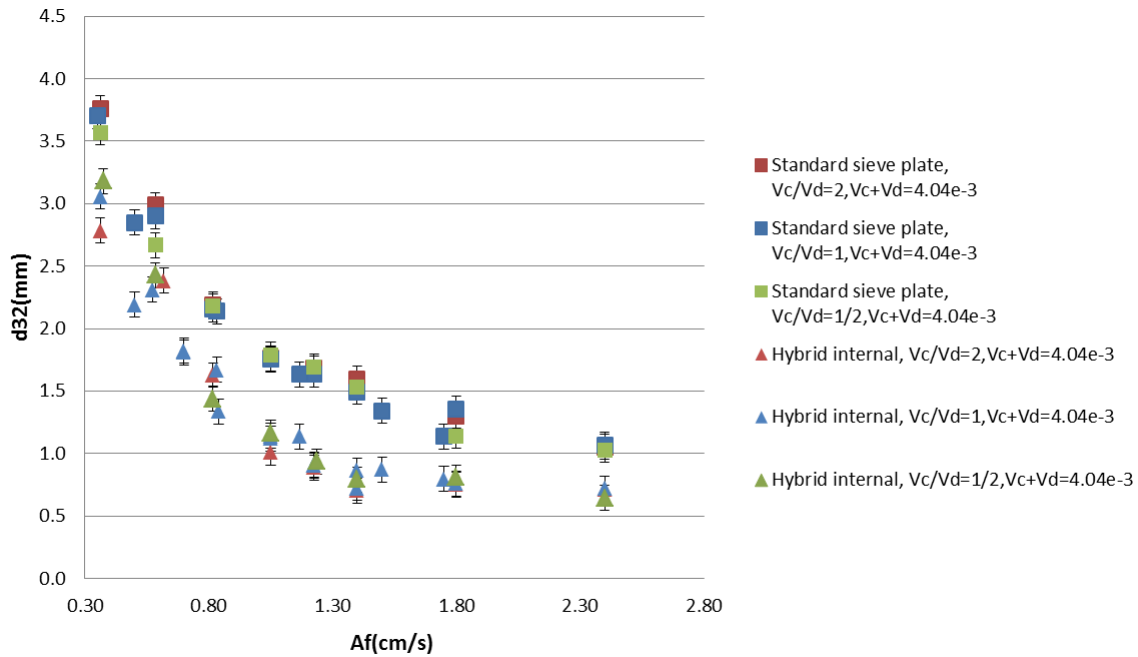

Fig. 4: Drop size (d32) of hybrid internal compared with standard sieve plate with variation of pulsation intensity (Af) and phase ratio (V_c/V_d).

3.3. Axial Dispersion Coefficient

Axial dispersion coefficients are measured by two-point method[8]. Experimental E_c of hybrid internal compared with that of standard sieve plate are shown in Fig. 5, in which the effect of pulsation intensity is considered, while pulsation intensity varies from 0.3 cm/s to 1.8 cm/s. E_c for both types of internals increase with an increase of pulsation intensity. The fact that the effect of pulsation intensity is not dramatic may be explained by that no experiment is conducted with high amplitude that exceeds the free spacing between stages, which will contribute to axial dispersion significantly.

Under all the conditions investigated, the E_c of the hybrid internal is lower than that of the standard sieve plate by around 1/2. This means the flow is more plug flow like for the hybrid internal, which results in better mass transfer efficiency. A possible explanation for this comparison is that adding the packing on the standard sieve plates reduces the free spacing between the stages, where axial dispersion is most likely to occur. The explanation is reasonable when considering that the ratio of free spacing between the two types of internals is about 1/2, which is the same as the ratio of experimental E_c variation.
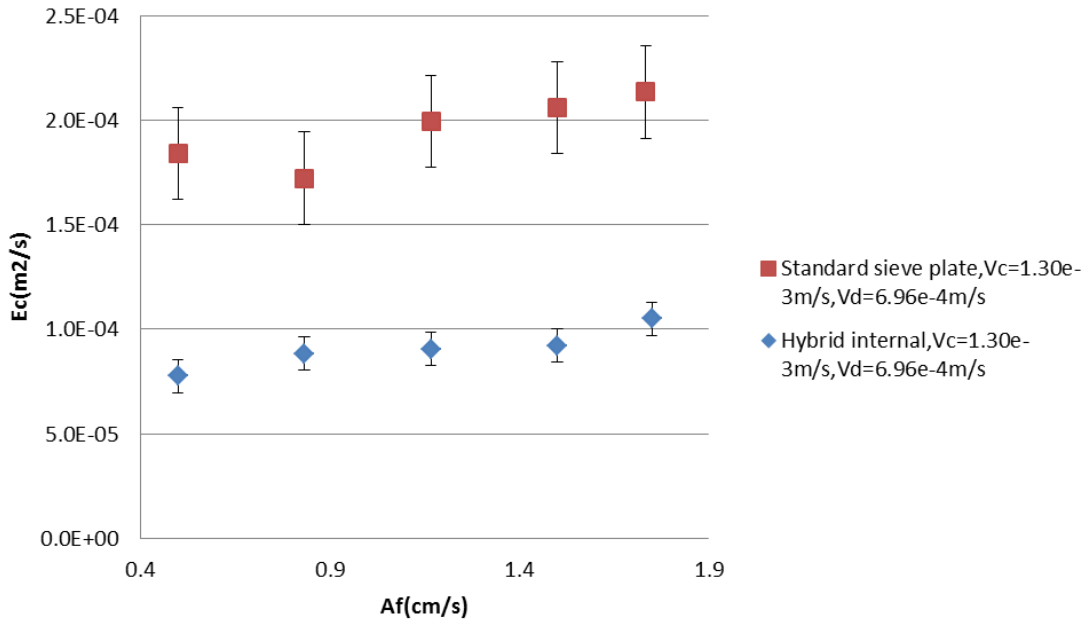
Fig. 5: Axial dispersion coefficients (E_c) of hybrid internal compared with standard sieve plate with variation of pulsation intensity (Af).
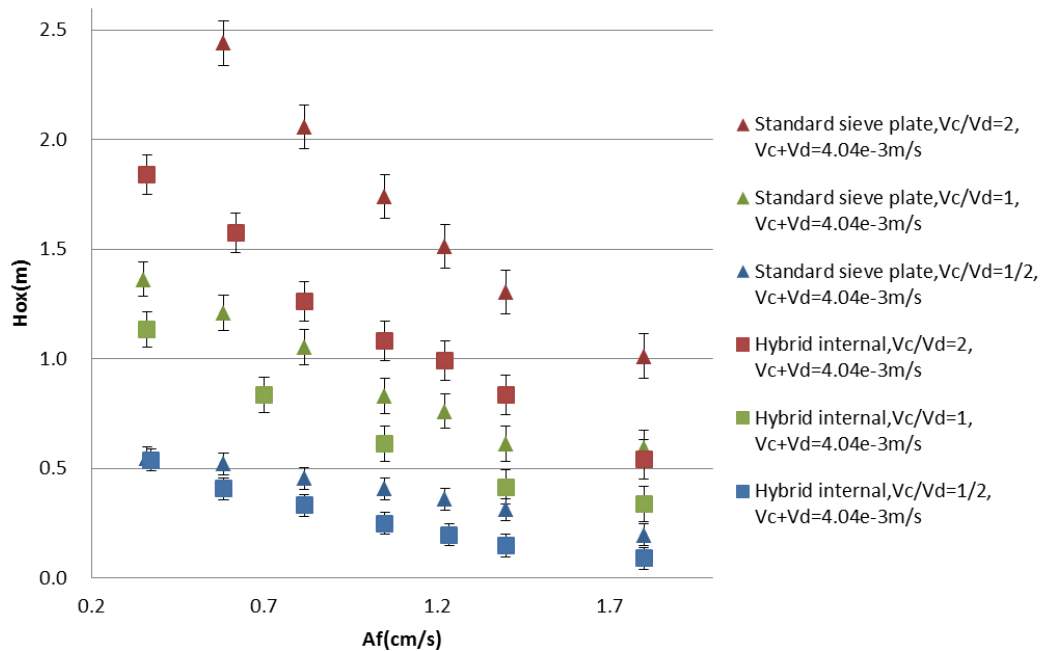
3.4. Mass Transfer Performance

Fig. 6: Height of overall mass transfer unit (H_{oxp}) of hybrid internal compared with standard sieve plate with variation of pulsation intensity (Af) and phase ratio (V_c/V_d).

Mass transfer performance is measured with steady state method[9] and shown with height of overall mass transfer unit (H_{oxp}). The H_{oxp} of hybrid internal compared with that of standard sieve plate is shown in Fig. 6, in which the effects of pulsation intensity and two phase superficial velocity are considered. Pulsation intensity varies from 0.3 cm/s to 1.8

cm/s and the continuous-dispersed phase ratio varies from 0.5 to 2 while total throughput of the two phases is kept constant. With an increase of pulsation intensity, H_{oxp} decreases accordingly for both types of internals under every V_c/V_d condition, indicating an improvement in mass transfer efficiency. For each type of internal, H_{oxp} decreases when V_c/V_d decreases from 2 to 0.5. Under all the conditions investigated, H_{oxp} of the hybrid internal is lower than that of the standard sieve plate by around 40%. It should be noted that under the best condition, H_{oxp} of the hybrid internal is as low as 0.2 m, which indicates very good mass transfer efficiency.

4. Conclusions

A novel hybrid internal for a pulsed solvent extraction column was designed by adding packing on standard sieve plates. Experiments were performed to compare its hydrodynamic and mass transfer performance with standard sieve plates. The conclusions from this study can be summarized as follows:

(1) Holdup of hybrid internal is higher than that of standard sieve plate by around 50%.
(2) Sauter mean diameter d_{32} of hybrid internal is smaller than that of standard sieve plate by around 40%.
(3) Axial dispersion coefficient E_c of hybrid internal is less than that of standard sieve plate by around 50%.
(4) Height of mass transfer unit H_{oxp} of hybrid internal is less than that of standard sieve plate by around 40%. This proves the adding of packing on plates to be a good way to improve mass transfer performance for standard sieve plates.
(5) The better mass transfer efficiency for hybrid internal can be explained by two factors: Larger specific mass transfer area resulted from higher holdup and smaller drop size, and less decrease of mass transfer efficiency from axial dispersion.

Acknowledgements

Nomenclature

A: Amplitude, m
a: specific interfacial area, m^2/m^3
d_{32}: Sauter-mean drop diameter, m
E: axial dispersion coefficient, m^2/s
f: frequency, Hz
H_{oxp}: height of apparent mass transfer unit, m
V: superficial velocity, m/s
x_d: volume fraction holdup of the dispersed phase, dimensionless

Greek Symbols

α: fractional free area of perforated plate, dimensionless
γ: interfacial tension, N/m
μ: viscosity, Pa.s
ρ: density, kg/m^3

Subscripts

c: continuous phase
d: dispersed phase

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