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Note

A new group contribution method for mineral concentration processes

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ABSTRACT

In this work, a group contribution model to predict the behavior of mineral concentration circuits is presented. The new model is an expansion and modification of an existing model in the literature (Sepúlveda et al., 2014). The modifications extend the number of process groups from 35 to 143, which makes it possible to extend the number of concentration circuits that can be represented from 1492 to over 274 million circuits and to increase the maximum number of stages from 6 to 9. The errors observed between the fitting and the prediction results of concentration circuits that were not included in the fitting verifies that the new model could be extremely useful in the design of mineral concentration circuits.

1. Introduction

Group contribution models assume that a certain property depends on the sum of the contributions made by structural groups. In this way, it is possible to estimate properties of many systems based on a reduced number of groups that constitute those systems. The primary application of these models is in designing chemical products that have the ability to form molecules based on groups of atoms. Additionally, these models have also been used to design separation processes based on fractional distillation (d'Anterroches and Gani, 2005) and recently to estimate the global recovery of concentration circuits (Sepúlveda et al., 2014). In this last work, a model was presented to estimate the recovery of 1492 circuits, which can incorporate 2–6 process stages, based on 35 process groups. To fit the model, data from 46 circuits were used. In the present work, this model is modified and extended to estimate the recovery of over 274 million concentration circuits, which can incorporate 2–9 concentration stages, based on 143 process groups. To fit the model, 293 concentration circuits were used. In addition to these advantages, the proposed contribution model includes circuit designs used in the process industry, the adjusted values α_i and β_i do not exhibit inconsistencies, and the model can relate the circuits from the database according to the number of process stages that are used.

2. Process groups

It is assumed that each concentration stage has two outlet streams: a concentrate and a tail. Fig. 1 shows a general diagram of the considered alternatives. The stages, *rougher* (R), *cleaner*$_1$ (C_1), *cleaner*$_2$ (C_2), and *cleaner*$_3$ (C_3), are defined as follows. Stage R processes the circuit feed, whose concentrate could be the final product or the feed to stage C_1. The concentrate generated by this last stage could be the final product or the feed to stage C_2. The concentrate generated in stage C_2 could be the final product or the feed to stage C_3. The concentrate generated by stage C_3 can only be the final product. The stages *scavenger*$_1$ (S_1) and *scavenger*$_2$ (S_2) are defined as follows. Stage S_1 is a stage that processes the tail R, and its tail stream could be the final tail or the feed to stage S_2. The tail generated by stage S_2 is the final tail of the process. This processing scheme is mandatory; for example, stage C_2 will only exist if the concentrate of stage C_1 is sent to this stage. These stages can also process other streams, which are optional and therefore constitute processing alternatives. For example, C_1 could also process concentrate streams generated by stages S_1, S_2, CS_{11}, SC_{11}, CS_{21}, or SC_{21} and the tail streams of stages C_2 and C_3; stage S_1 could process tail streams from stages C_1, C_2, C_3, CS_{11}, SC_{11}, CS_{21}, SC_{21}, or SS_{12}.

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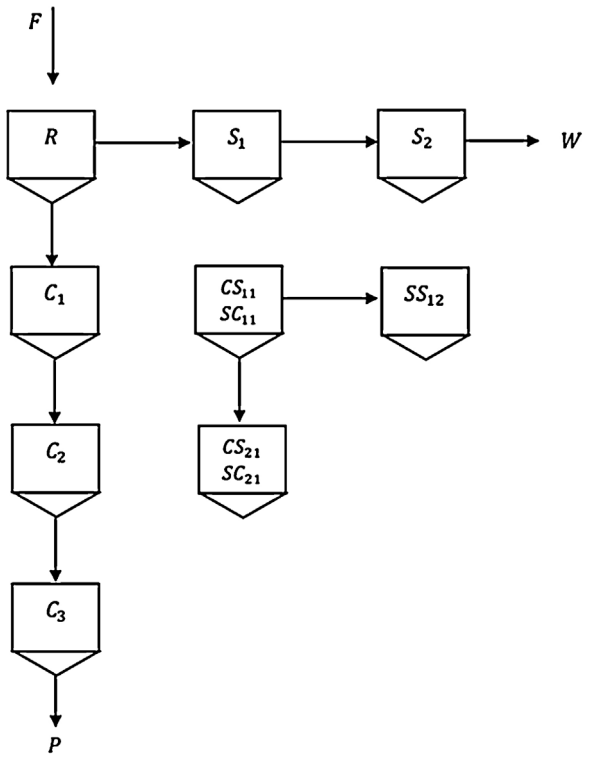

Fig. 1. General scheme of the concentration process.

Table 1, which represents the origin–destination matrix of concentrates and tails, shows all processing alternatives; when read by rows, the destination of concentrates (X) and tails (O) of each stage can be obtained, and when read by columns, all the concentrates and tails that are fed to each stage can be obtained. Stages R, C_1, C_2, C_3, S_1, and S_2 were included in the work by Sepúlveda et al. (2014).

In the present work, intermediate process stages are introduced: *cleaner–scavenger*$_{11}$ (CS_{11}), *cleaner–scavenger*$_{21}$ (CS_{21}), *scavenger–cleaner*$_{11}$ (SC_{11}), *scavenger–cleaner*$_{21}$ (SC_{21}), and *scavenger–scavenger*$_{12}$ (SS_{12}). The *cleaner–scavenger* stage primarily processes tails of the cleaner stages, and the *scavenger–cleaner* stage primarily processes concentrates of scavenger stages. The subscripts indicate the position of the process stages, such that CS_{11} and SC_{11} are at the same level as stages C_1 and S_1, and stages CS_{21} and SC_{21} are at the same level as stages C_2 and S_1. These stages can process other streams (tails and concentrates), as indicated in Table 1, such that the *cleaner–scavenger*$_{11}$ stage (CS_{11}) processes the tails of stages C_1, C_2, C_3, CS_{21}, and SC_{21} and the tails of stages S_1, S_2, and SS_{12}; the *scavenger–cleaner*$_{11}$ stage (SC_{11}) processes the concentrates of stages S_1, S_2, and SS_{12} and the concentrates of stages CS_{21}, and SC_{21}.

Table 1 shows all the possible destinations of concentrates (X) and tails (O) of each stage. In this table, P and W represent the final concentrate and final tail of the circuit, respectively. The number of circuits that can be represented correspond to 2 with two stages, 12 with three stages, 660 with four stages, 17,832 with five stages, 299,264 with six stages, 4,377,600 with seven stages, 51,840,000 with eight stages, and 217,728,000 with nine stages, which totals 274,263,370 circuits.

In the group contribution model, the behavior of a concentration circuit is predicted from the contribution of each process group. These process groups are a function of the process stages and the destinations of their products (concentrates and tails). In Table 1, 145 process groups can be identified when combining concentrate and tail destinations. For example, the RC_1S_1 group corresponds to stage R, whose concentrate is sent to stage C_1, and its tail is sent to stage S_1. Out of the 145 potential groups, only 143 groups were considered; groups (RPW) and ($SC_{21}PSC_{11}$) were discarded because the former does not interact with the rest of the groups and the latter is extremely rare. With these 143 groups, concentration circuits that incorporate 2–9 process stages can be generated. Table 3 lists all the considered groups. Because each group not only includes the flotation stage but also the destination of its concentrate and tail, each group carries topological information with it.

3. Recovery models

To estimate the circuit recovery, two models are proposed, which depend on the recovery values in the rougher stage (Sepúlveda et al., 2014). For high recoveries (0.63–1) and low recoveries (0.1–0.37) in the rougher stage, the following model is proposed:

$$Rc_j = \frac{\sum_{i=1}^{n} \Lambda_{i,j}}{\sum_{k=1}^{9} r_k N_T + \sum_{k=1}^{3} c_k N_C + \sum_{k=1}^{2} s_k N_S + \sum_{k=1}^{3} cs_k N_{CS}} \quad (1)$$

where Rc_j is the recovery of species j in the circuit; $\Lambda_{i,j}$ is the contribution of group i; N_T is the total number of groups in the circuit; N_C is the total number of cleaner stages in the circuit; N_S is the total number of scavenger stages in the circuit; and N_{CS} is the total number of intermediate stages in the circuit. Note that the maximum number of N_T, N_C, N_S, and N_{CS} is 9, 3, 2, and 3, respectively.

For intermediate recoveries (0.37–0.63) in the rougher stage, the following model is used:

$$Rc_j = \sum_{i=1}^{n} \Lambda_{i,j} + \sum_{k=1}^{9} r_k \ln(N_T) + \sum_{k=1}^{3} c_k \ln(N_C + 1) + \sum_{k=1}^{2} s_k \ln(N_S + 1) + \sum_{k=1}^{3} cs_k \ln(N_{CS} + 1) \quad (2)$$

Table 1
Origin–destination matrix of concentrates (X) and tails (O) to generate the 143 process groups.

	R	C_1	C_2	C_3	S_1	S_2	CS_{11}	SC_{11}	SS_{12}	CS_{21}	SC_{21}	P	W
R		X			O							X	O
C_1	O		X		O	O	O			O		X	
C_2	O	O		X	O	O	O			O		X	
C_3	O	O	O		O	O	O			O		X	
S_1	X	X	X	X		O	X	X					O
S_2	X	X	X	X	X		X	X					O
CS_{11}	O	X			O	O			O	X	X	X	O
SC_{11}	O	X	X	X	O	O			O	X	X		
SS_{12}	O				O	O	X	X					O
CS_{21}	O	X	X		O	O	O	O	O			X	O
SC_{21}	O	X	X	X	O	O	O	O	O			X	