Supporting Information

Sodium Oleate Assisted High-Efficient Utilization of Phosphate Ores: Improved Leaching Performance and Reduced Metallic Impurities

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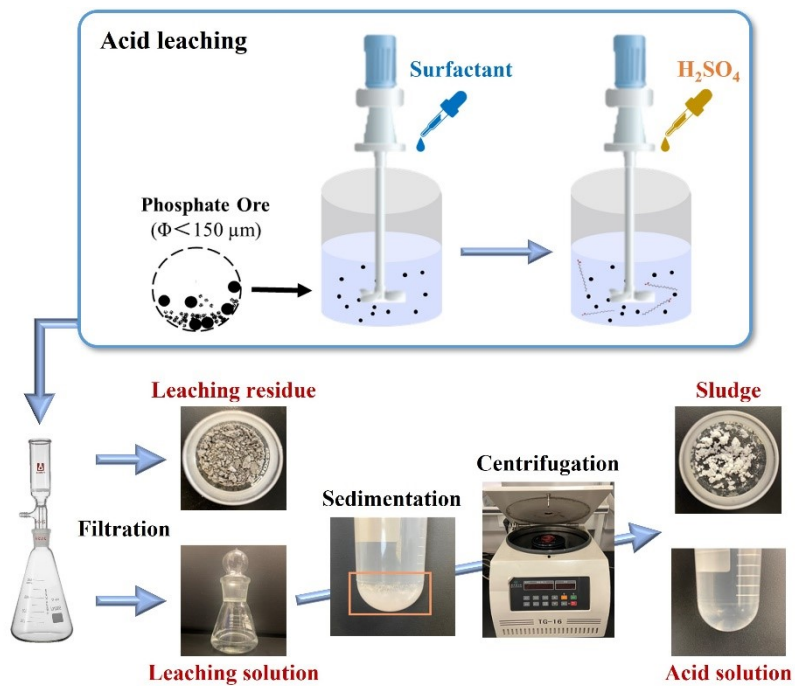[*] Corresponding Author: lrl@cqu.edu.cn (R. Liu)

S1. Calculation of Adsorption Energy

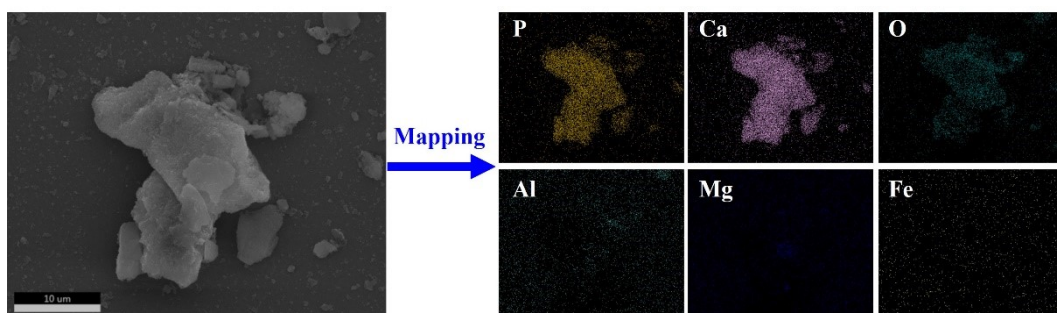The equation for the calculation of adsorption energy is shown below.

$$\Delta E_{ads} = E_{PG-SOL} - E_{PG} - E_{SOL}$$ (S1)

where ΔE_{ads} is the adsorption energy (eV); $E_{PG\text{-}SOL}$, E_{PG}, and E_{SOL} are the energy of PG-SOL complex (eV), energy of PG (eV), and energy of SOL (eV), respectively.

S2. Additional Figures and Tables

Figure S1. Schematic of the acid leaching and the sedimentation of leaching solution.

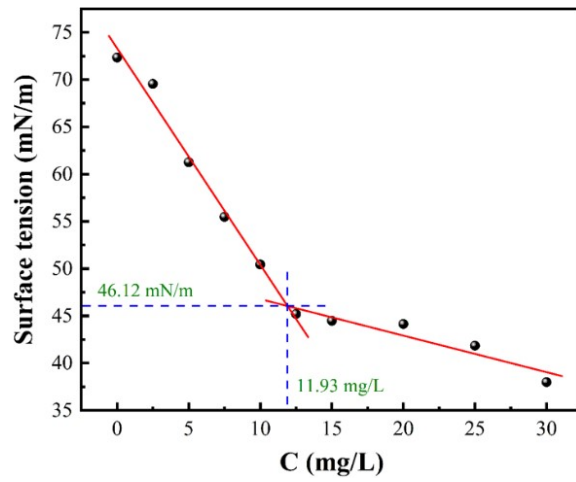**Figure S2.** SEM-EDS analysis performed on the PO.

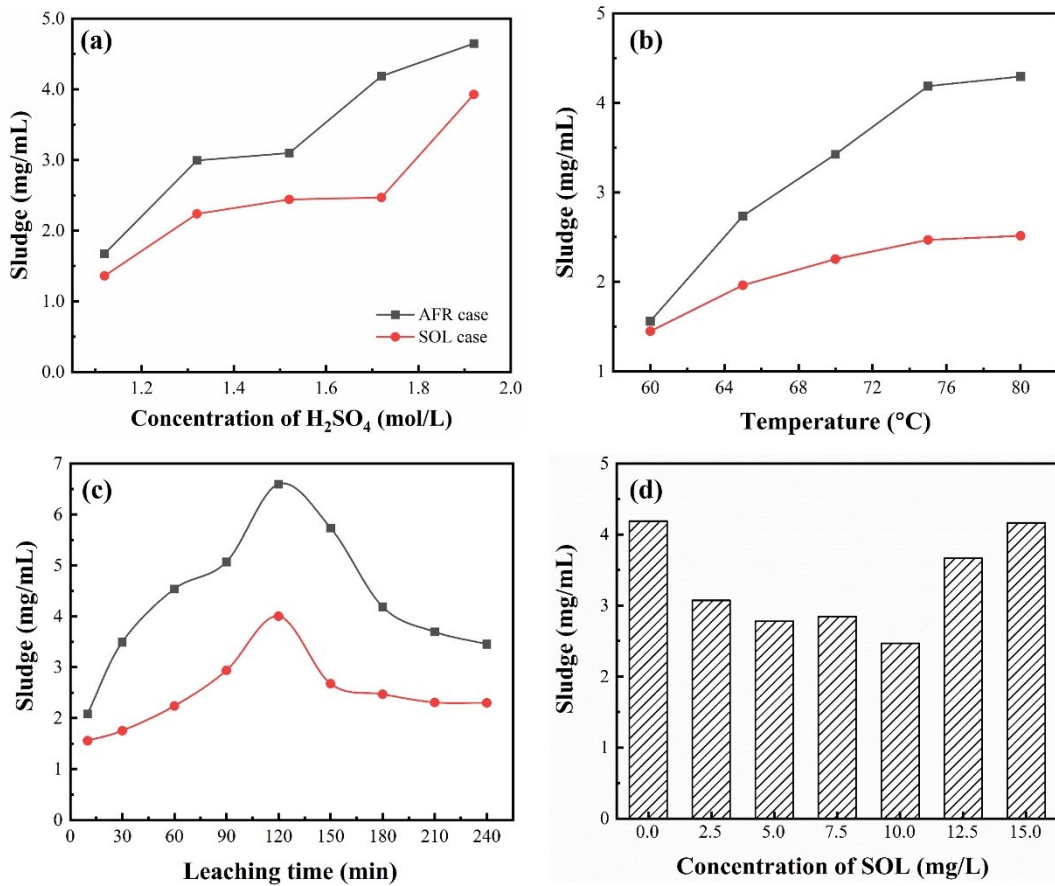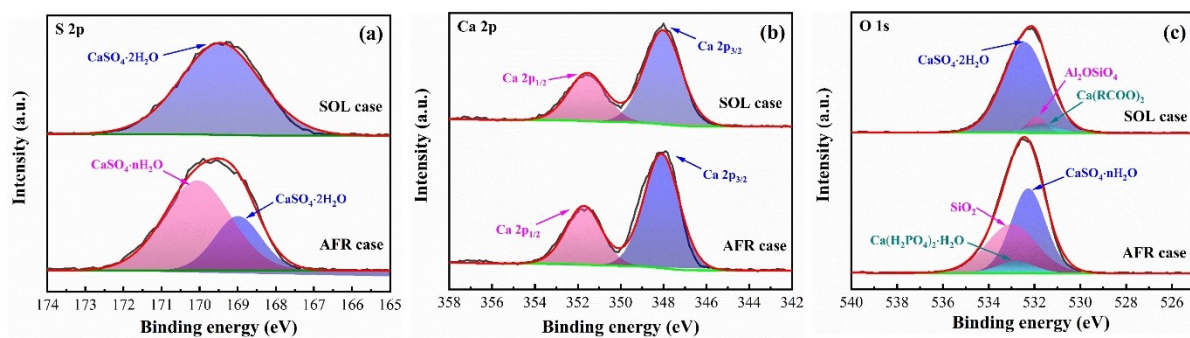**Figure S3.** Equilibrium surface tension curves of SOL solutions.

Figure S4. The effect of (a) sulfuric acid concentrations, (b) leaching temperature, (c) leaching time, and (d) surfactant concentration on the amount of sludge.

Figure S5. XPS spectra for the sludge samples: (a) S 2p, (b) Ca 2p, and (c) O 1s.
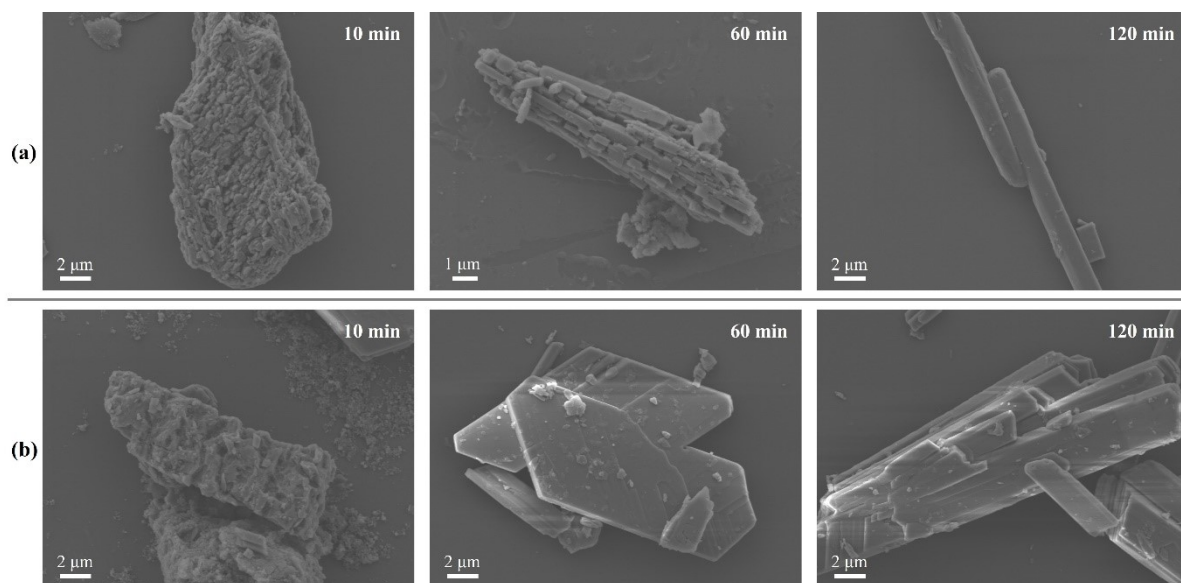
Figure S6. SEM analysis of the leaching residue in (a) AFR and (b) SOL cases at different leaching time.
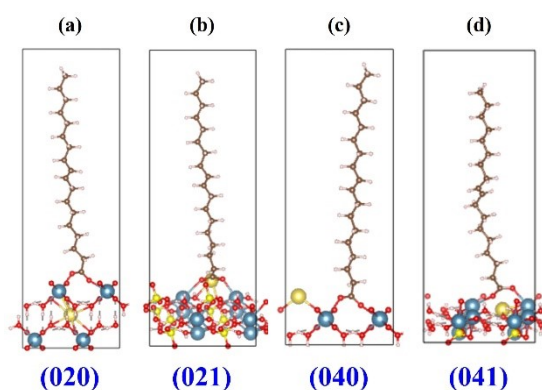
Figure S7. Adsorption configurations of SOL on (020), (021), (040), and (041) surfaces of PG.

Table S1. Details of the chemical reagents.

Chemical	Formula	Molecular weight (g/mol)	Purity	Supplier
CTAB	$C_{19}H_{42}BrN$	364.3	98%	KESHI
PVP	$(C_6H_9NO)_n$	> 2500	≥ 99%	KESHI
SOL	$C_{18}H_{33}NaO_2$	304.4	≥ 98.5%	KESHI
LSB	$C_{17}H_{37}NO_3S$	335.5	98%	Aladdin
SDBS	$C_{18}H_{29}NaO_3S$	348.5	≥ 90%	Guangfu
Sulfuric acid	H_2SO_4	98.08	≥ 95.0%	KESHI

Table S2. Experimental conditions.

Experimental parameter	Values
Surfactant concentration (mg/L)	2.5, 5*, 7.5, 10, 12.5, 15
Sulfuric acid concentration (mol/L)	1.12, 1.32, 1.52, 1.72*, 1.92
Leaching temperature (°C)	60, 65, 70*, 75, 80
Leaching time (min)	30, 60, 90, 120, 150, 180*, 210, 240

* Kept constant when other parameters are varied.

Table S3. Analysis of variance for investigated experimental variables.

Variable	C_{SOL} (mg/L)	C_{H2SO4} (mol/L)	T (°C)	t (min)
p-value Prob > F*	0.0184	0.0017	0.0093	0.0308

* Value less than 0.05 indicates the variable is significant; values greater than 0.10 indicates the variable is not significant.

Table S4. XPS data.

	Binding energy (eV)	Formula
P 2p	133.8	$Ca_3(PO_4)_2$
	134.1	NaH_2PO_4
	135.2	H_3PO_4
S 2p	169.0	$CaSO_4 \cdot 2H_2O$
	169.5	$CaSO_4 \cdot 2H_2O$
	170.1	$CaSO_4 \cdot nH_2O$
Ca 2p	348.0	Ca 2p3/2
	348.1	Ca 2p3/2
	351.6	Ca 2p1/2
	351.7	Ca 2p1/2
O 1s	531.6	$Ca(RCOO)_2$
	531.9	$Al_2O_3 \cdot SiO_2$
	532.3	$CaSO_4 \cdot nH_2O$
	532.4	$CaSO_4 \cdot 2H_2O$
	532.8	$Ca(H_2PO_4)_2 \cdot H_2O$
	533.0	SiO_2

Table S5. Surface elemental compositions (wt.%) of the sludge.

Sludge	C	Ca	S	O	Si	P
AFR case	17.61	10.09	12.15	54.35	3.04	2.75
SOL case	24.66	9.84	11.59	49.21	4.31	0.39

Table S6. Elemental composition of the leaching residues.

Composition	SO_3	CaO	P_2O_5	SiO_2	Al_2O_3	K_2O	Fe_2O_3	MgO	Others
AFR (wt%)	50.14	37.84	4.64	4.58	0.96	0.58	0.47	0.31	0.48
SOL (wt%)	45.77	44.26	1.13	5.62	1.02	0.66	0.67	0.22	0.65

Table S7. Structural information of the unit cell of the PG crystal.

Parameter	a	b	c	α	γ	β	Space group
Value	11.3580 Å	30.4040 Å	13.0440 Å	90°	118.43°	90°	I2/C

Table S8. Structural information of the unit cell of the fluorapatite crystal.

Parameter	a	b	c	α	γ	β	Space group
Value	18.7260 Å	18.7260 Å	6.8780 Å	90°	90°	120°	P63/M