Gold and Silver Leaching in Alkaline Amino Acids Solutions

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Outline

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- Target Properties of Lixiviants
- Amino Acids WHY?
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- Alkaline System WHY?
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  - Effect of Amino Acids
  - Effect of Glycine Concentration
  - Effect of Silver Content
  - Effect of Temperature
  - Effect of pH

Outline

- **Leaching at Low Glycine Concentration**
  - Effect of Glycine Concentration
  - Effect of Temperature
  - Effect of Peroxide
- **Gold and Silver adsorption onto activated carbon**

Introduction

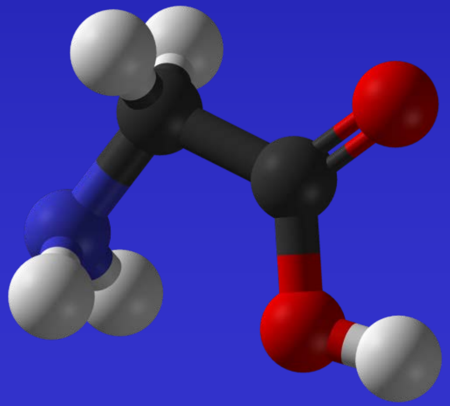
- Different types of reagents have been used as lixiviants in precious metals leaching:

- Cyanide - Thiosulfate -Thiocyanate - Chloride - Thiourea.

- Of these, cyanide remains the only reagent that is applied on an industrial scale for gold and gold-silver ores. However, cyanide use poses a number of challenges:
  - Toxicity
  - Transport restrictions
  - Restriction on use of cyanide in certain jurisdictions (e.g. Cadia in NSW, Montana & California, USA, Europe)
  - Large increases in cyanide consumption with decreasing gold grades in ores

What is an Amino Acid?

- Building block of all proteins
- About 500 different types.
- Simpler amino acids are produced in bulk quantities and available at low prices.
- Glycine is simplest amino acid (amino acetic acid).
- Sweet tasting, non-toxic, occurs in human body.
- Glycine has the following structure:



Black: Carbon
White-grey: Hydrogen
Blue: Nitrogen
Red: Oxygen

What are the requirements for a good lixiviant?

Target properties of lixiviants

- Appropriate leach rate for mode of leaching.
- Toxicity and biodegradability.
- Cost, bulk availability and ease of production.
- Accessibility, including legal and regulatory constraints.
- Criticality of supply.
- Volatility of reagents.
- Ability to recover and recycle for reuse.
- Control and complexity of the leaching chemistry.

Target properties of lixiviants (continued)

- Solubility and stability of the lixiviant in water
- Solubility and stability subsequent metal-lixiviant complexes.
- Transportability by ship, rail or truck and transport restrictions and risk.
- Ability to destroy excess reagent or unwanted metal-lixiviant complexes in a controlled and cost-effective manner.

Do Amino Acids Fulfil These Requirements?

Pros and cons of Amino acids system

Non-toxic	☑	Potential for recovery and reuse	☑	Operated under dilute and concentrated modes	☑
Environmentally benign	☑	Enzymatically/biologically destructible	☑	Thermally stable and non-volatile	☑
High affinity for Au, Ag and Cu	☑	Reagent Cost	☑	Application to various leaching modes	☒
Simple chemistry	☑	Biologically producible	☑	Materials of construction	☑
Selective over non-sulfide gangue minerals	☑	Transportability & logistics, trade restrictions	☑	Recoverable using conventional technology	☑
Leach rate	☒	Stability over wide pH and redox range	☑	Heat requirement (Au) &(Cu)	☒ ☑

The alkaline-glycine system

- Glycine has a FOB price of $1,800-$2,400 per ton.
- H_2O_2 , Oxygen and Cu(II) is already in use for many gold leaching operations.
- Lime is already in use.
- Glycine is readily available in bulk quantities: Food grade glycine of around 488,000 tonnes was produced in 2010.
- The gold glycinate complex is stable over a wide pH-Eh range.

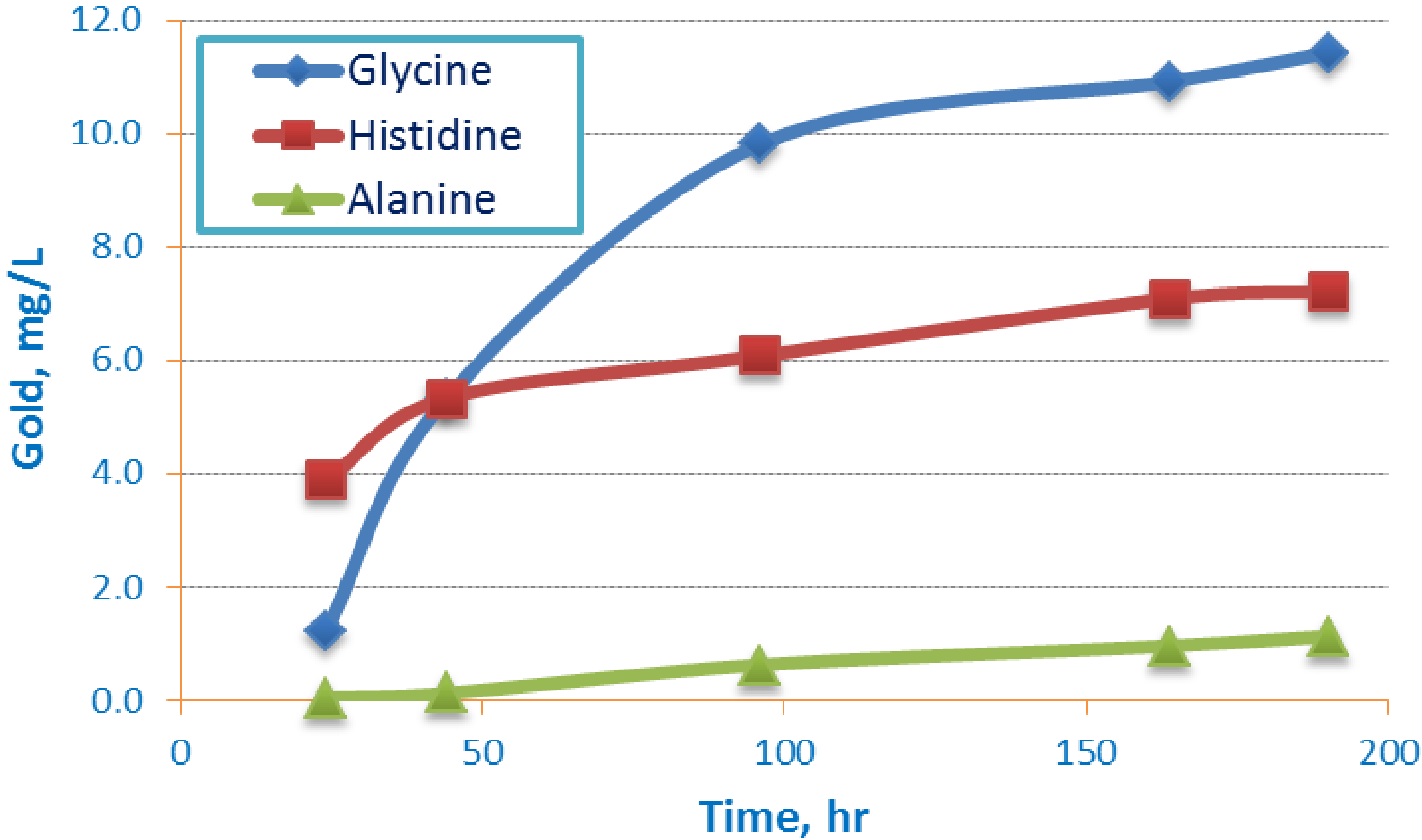
Potential alkaline lixiviant systems

Ammoniacal-Cu-Thiosulfate

- pH ~ 9.5
- Understanding of chemistry and mechanism still unclear.
- High thiosulfate consumption.
- Inability to reuse and recycle.
- High ammonia concentration required to balance Cu in solution and prevent tenorite (CuO) precipitation.
- Small stability range.
- Polythionates problematic.
- Significant variation in gold recovery from various ores.
- Need for ion exchange technology for Au recovery.

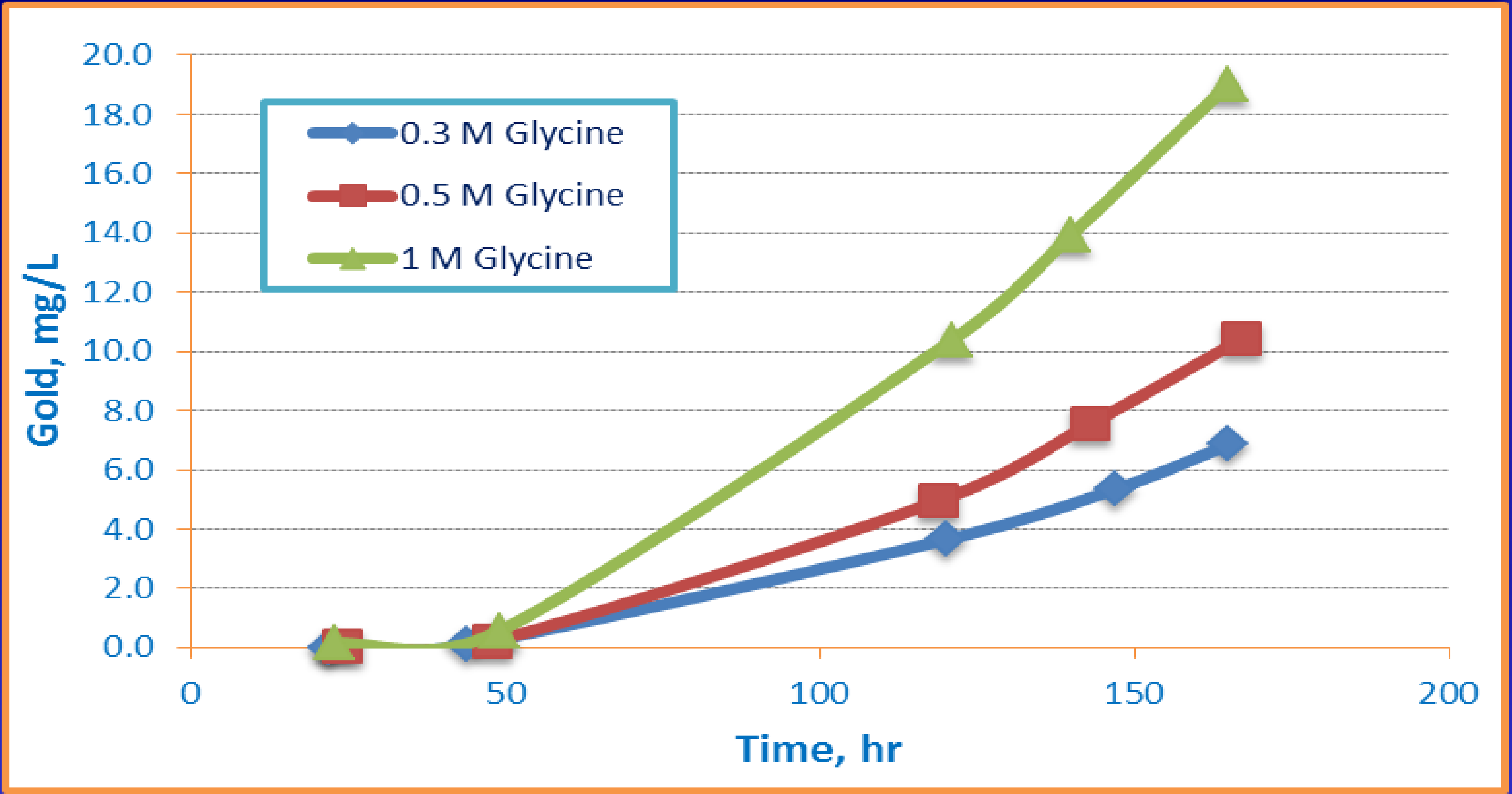
Gold Leaching

Amino Acids Type



0.5M amino acid, 1% H_2O_2, pH 11, at 60 °C

Effect of Glycine Concentration



Glycine, M	Au, 10^3 x μmol/m^2.s
0.30	11.3
0.50	16.9
1.00	31.3

Glycine, 1% H_2O_2, pH 10, 60 °C

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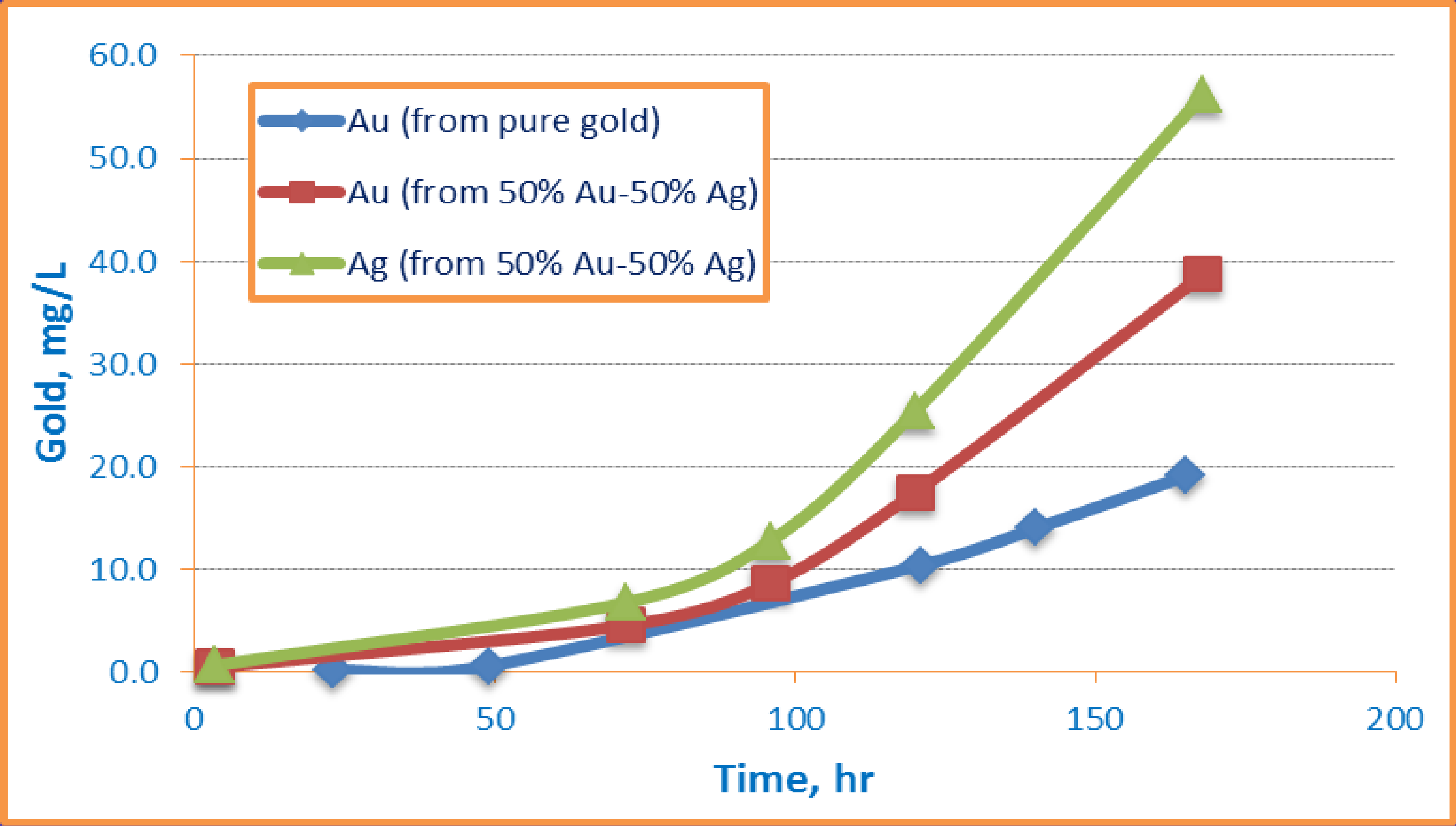
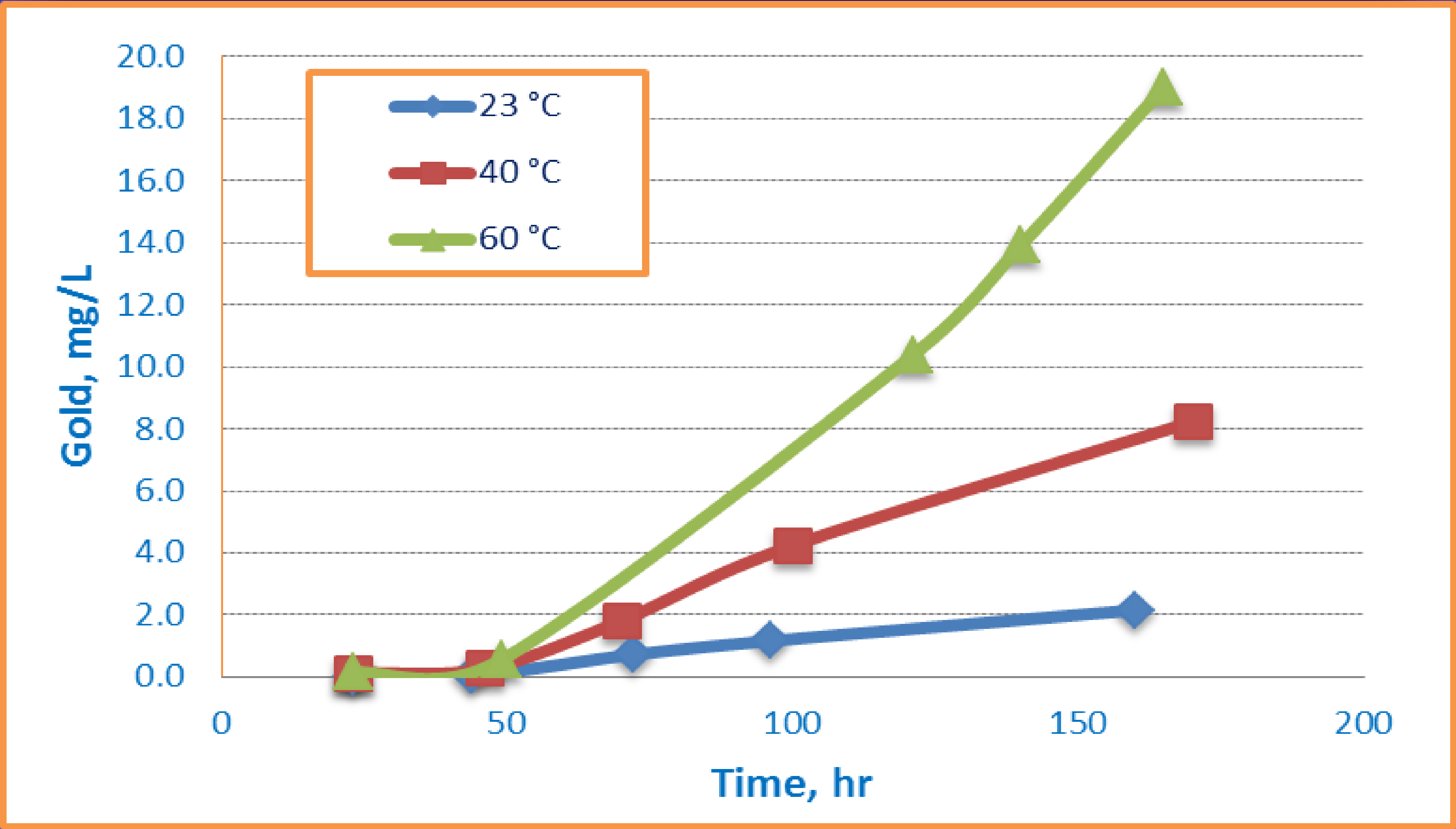
Effect of Silver



Au, Ag Source	Au, 10^3 x µmol/m^2.s
Gold from (pure gold sheet)	31.3
Gold (from 50% Au- 50% Ag)	185
Silver (from 50% Au- 50% Ag)	247

1M Glycine, 1% H_2O_2, pH 10, 60 °C

Effect of Temperature



1M Glycine, 1% H_2O_2, pH 10, 60 °C

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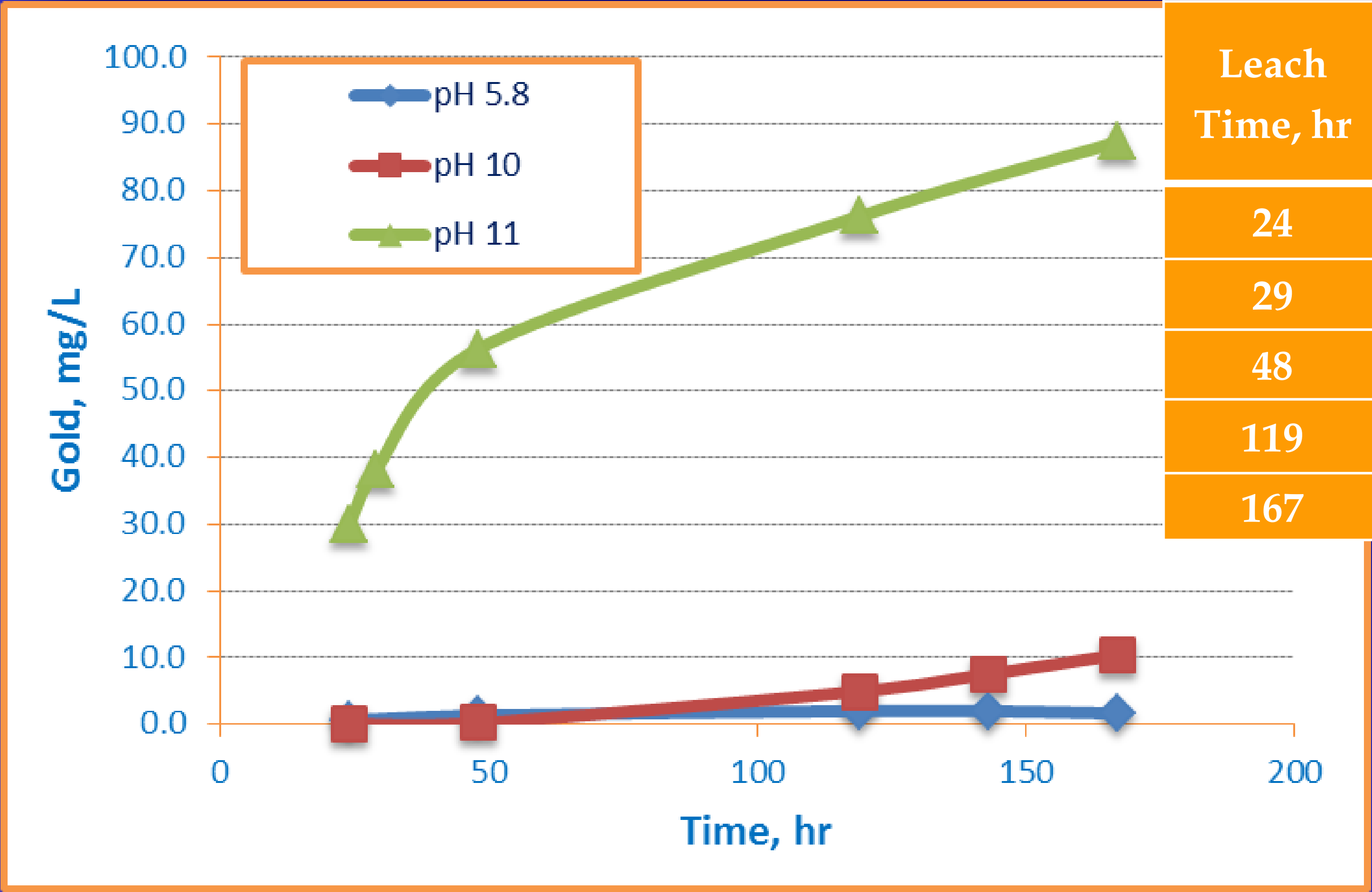
Effect of pH



Leach Time, hr	Au, 10^3 x μmol/m².s		
	pH 5.8	pH 10	pH 11
24	8.11	0.59	352
29	8.75	1.30	367
48	5.13	11.47	322
119	4.19	14.34	174
167	3.02	16.93	142

0.5M glycine, 1% H_2O_2, pH, and 60 °C

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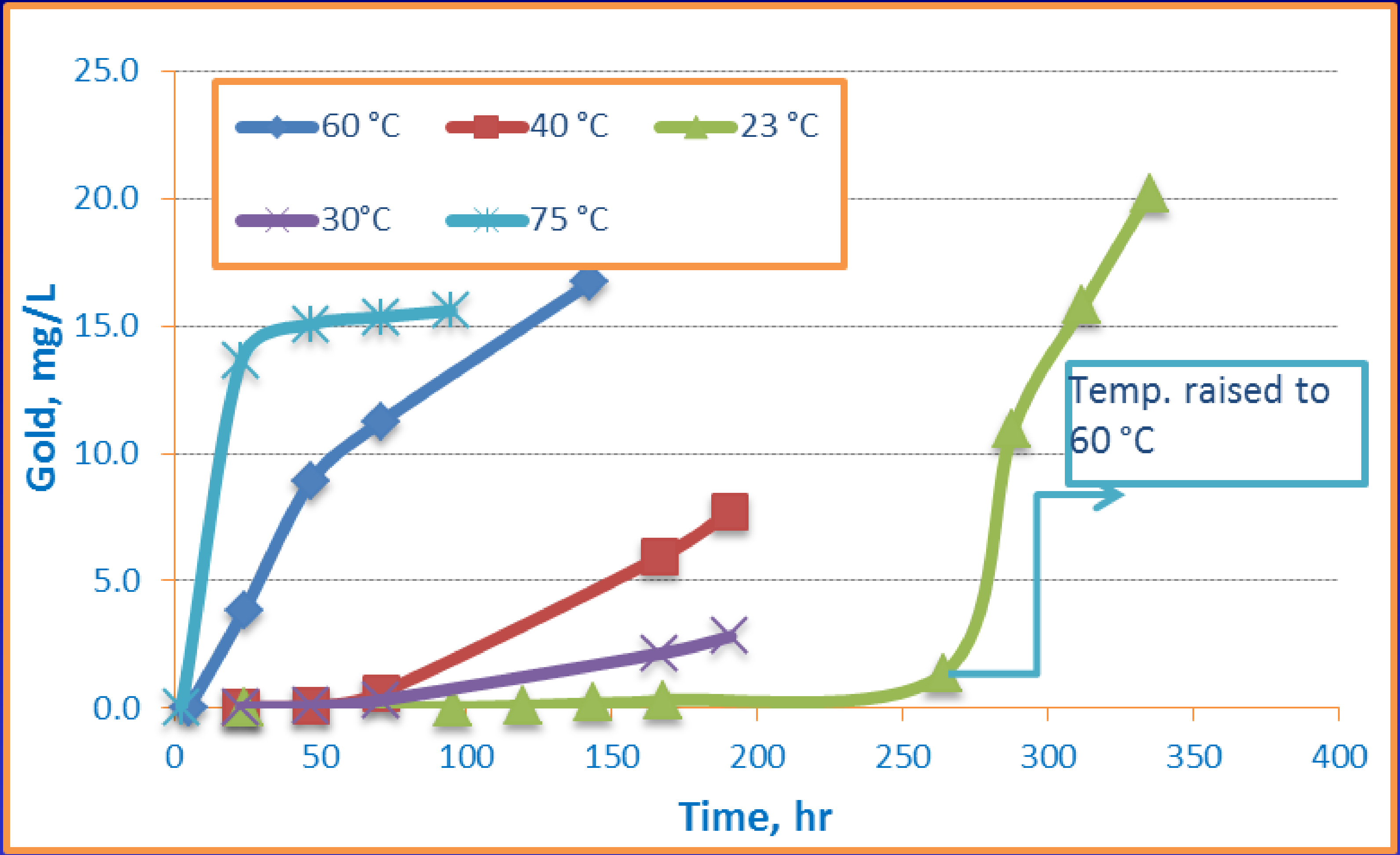
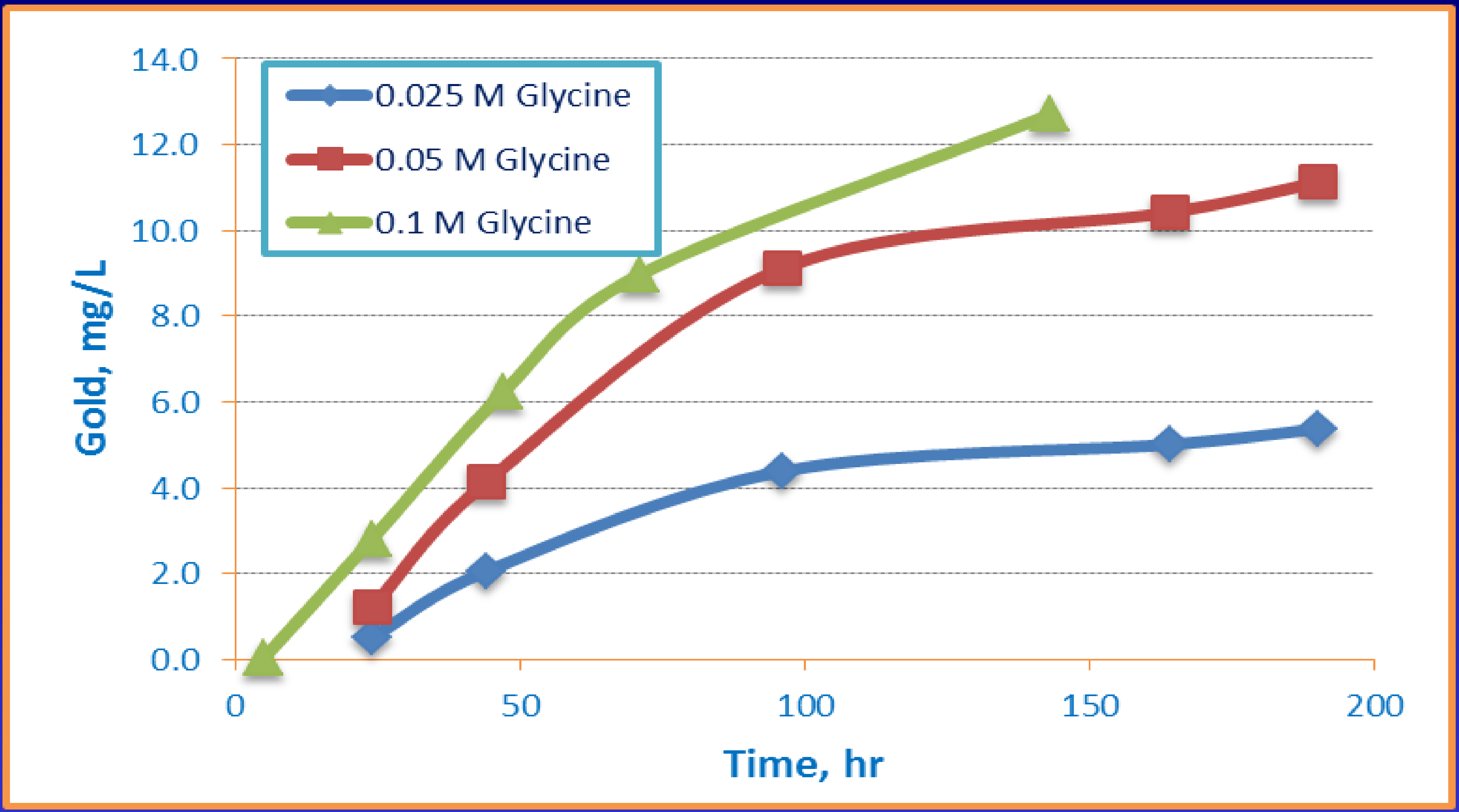
Leaching at low Glycine concentrations



0.1M glycine, 1% H_2O_2, initial pH 11.5

Effect of glycine concentration in low concentration range on gold leaching



Glycine, 1% H_2O_2, pH 11, 60 °C

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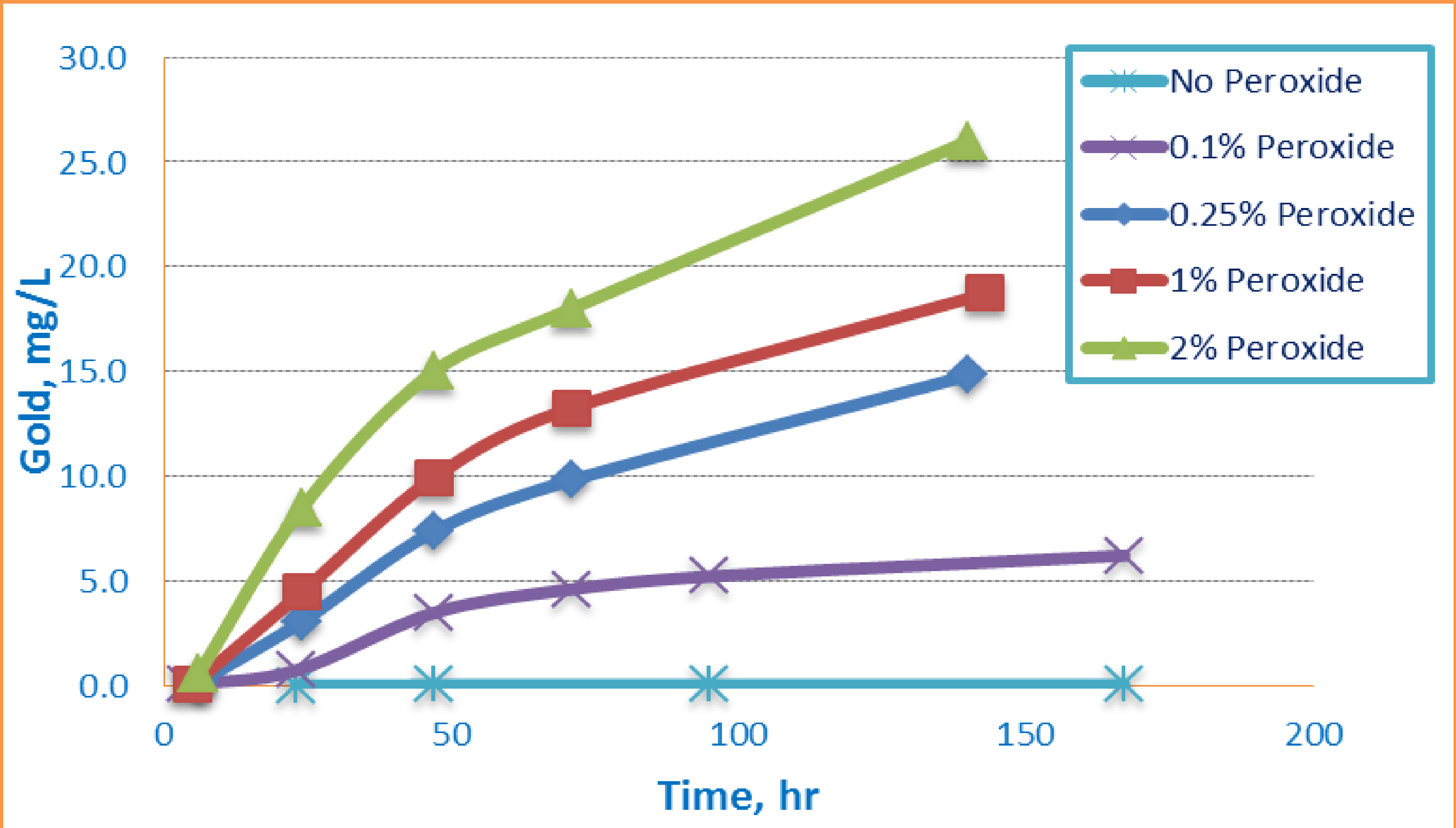
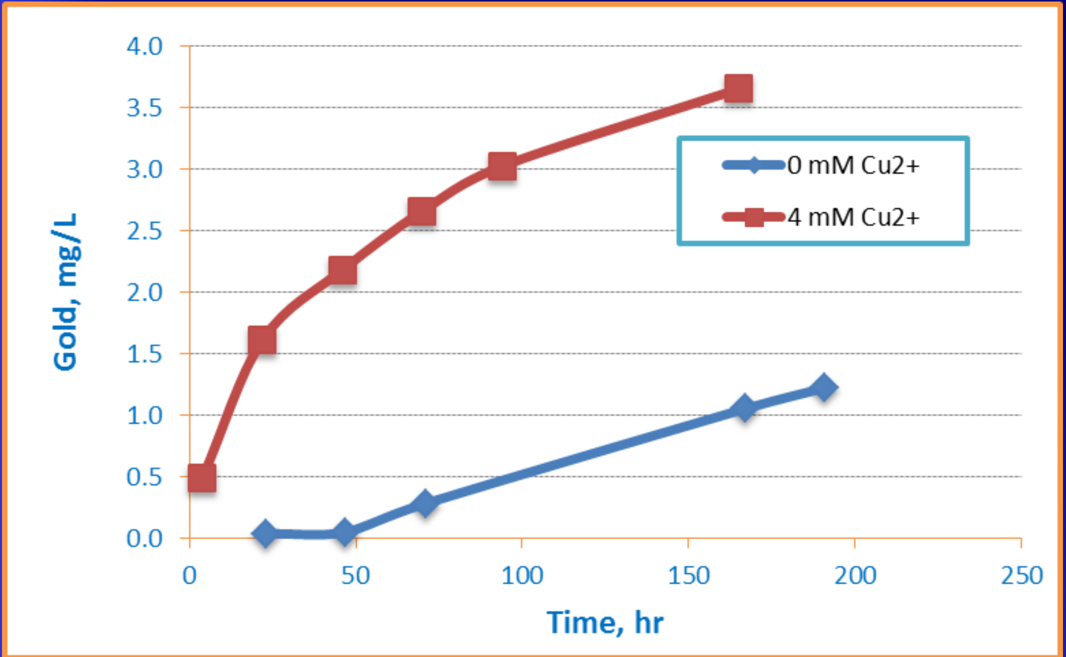
Effect of H_2O_2 concentration

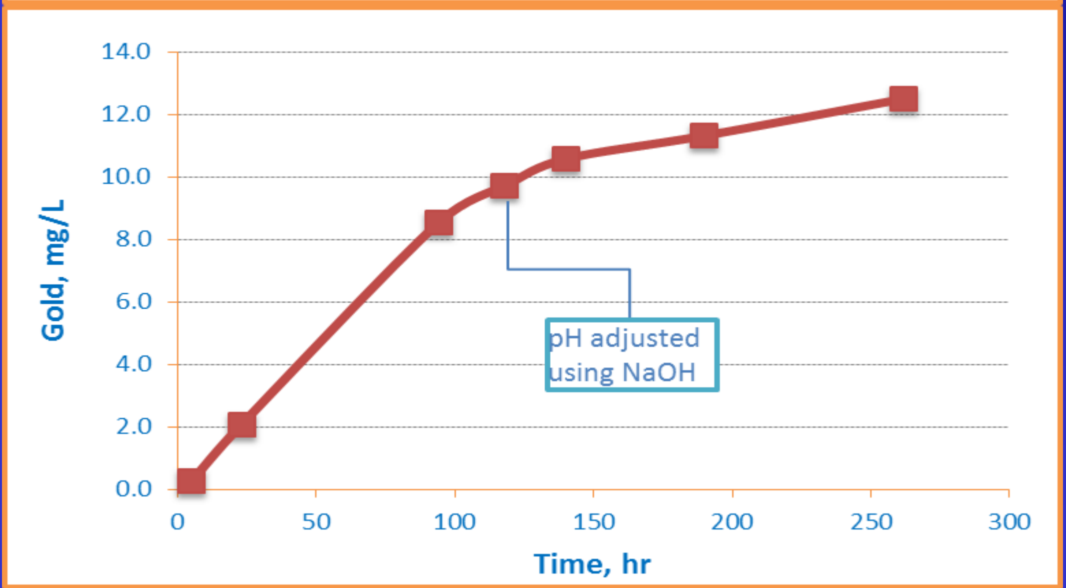


0.1M glycine, different percentages of H_2O_2, pH 11.5, 60 °C

Catalytic effect of cupric ions

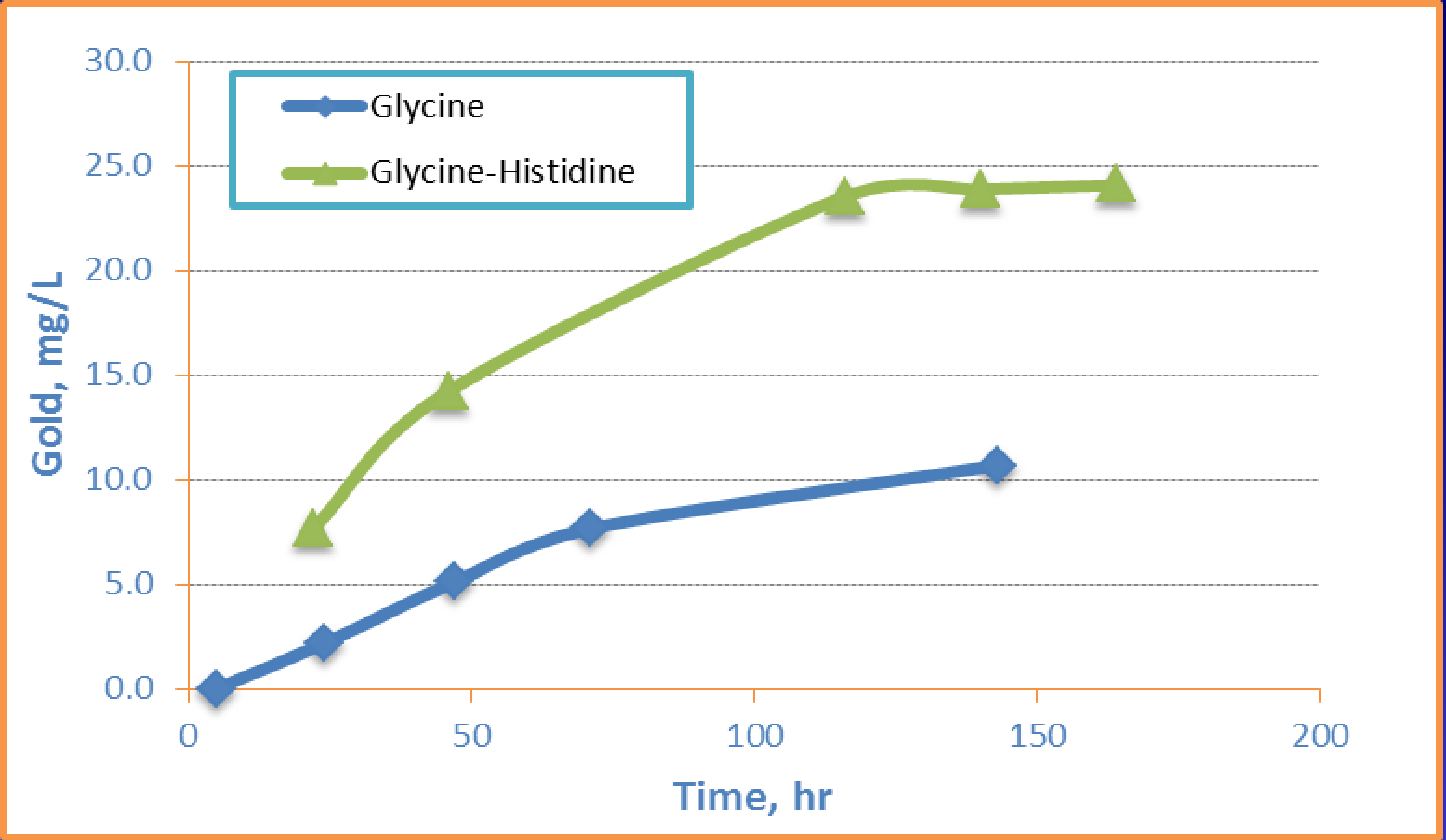


0.1M glycine, 0.1% H_2O_2, pH 11, at 30 °C



0.1M glycine, 0.3% H_2O_2, 4 mM Cu^{2+}, pH 11.9 and 30 °C

Synergistic effect of amino acid mixtures



0.1M amino acid, 1% H_2O_2, pH 11, at 60 °C

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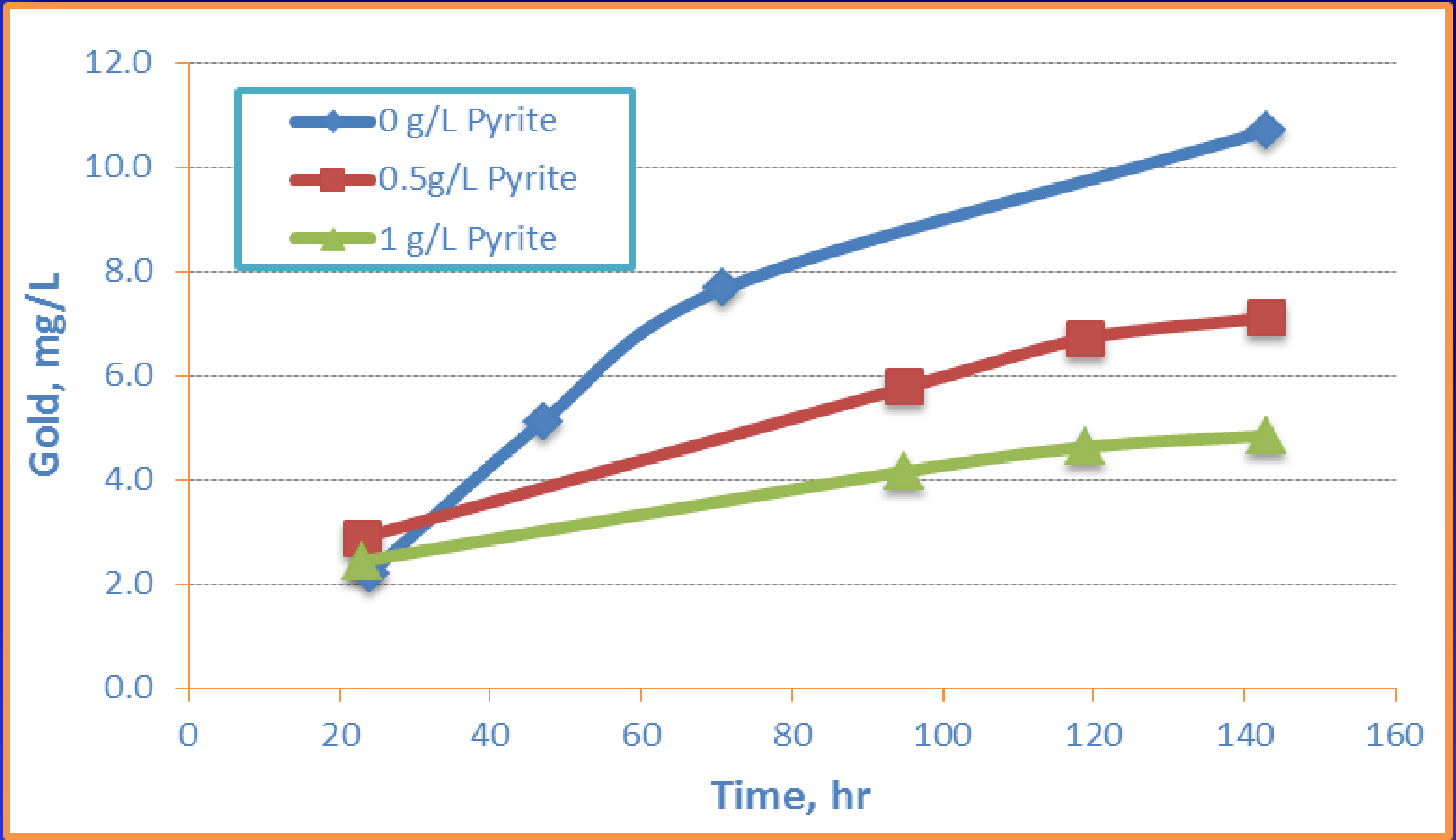
Effect of pyrite on gold dissolution from glycine-peroxide solutions



0.1M Glycine, 1% H_2O_2, pH 11, at 60 °C

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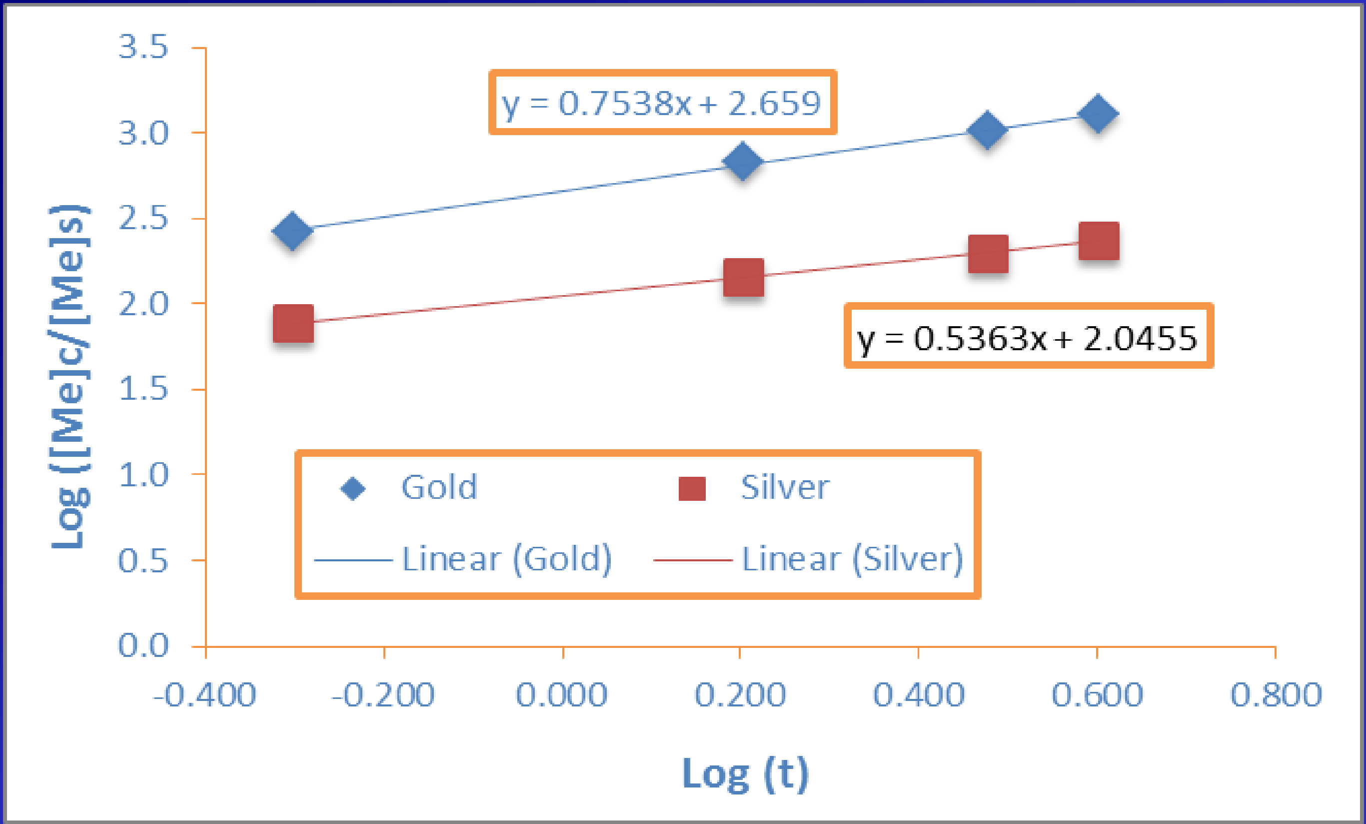
Metal recovery: Adsorption of metal glycinates onto activated carbon

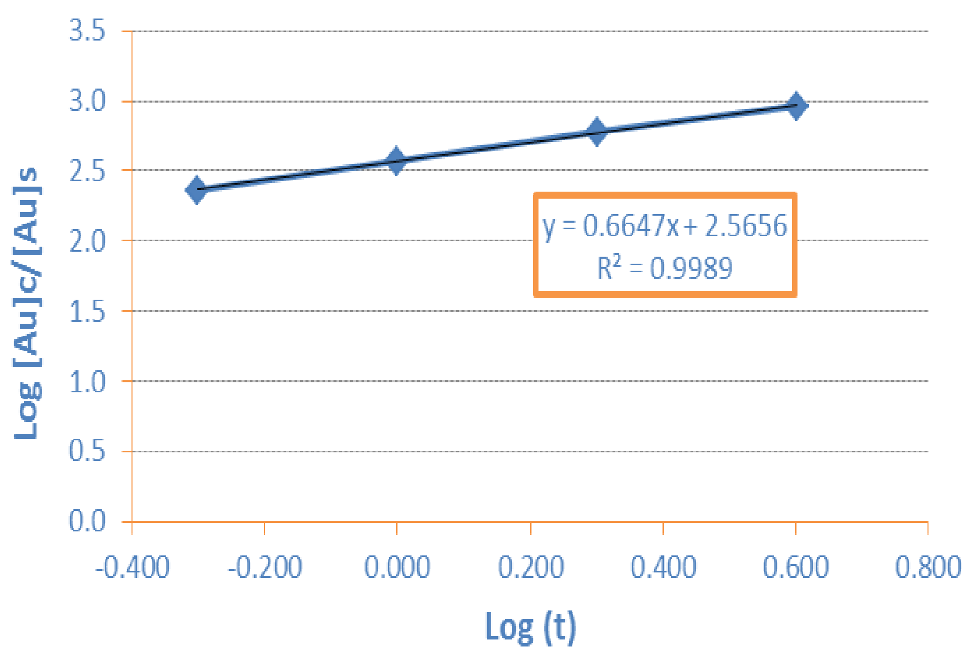


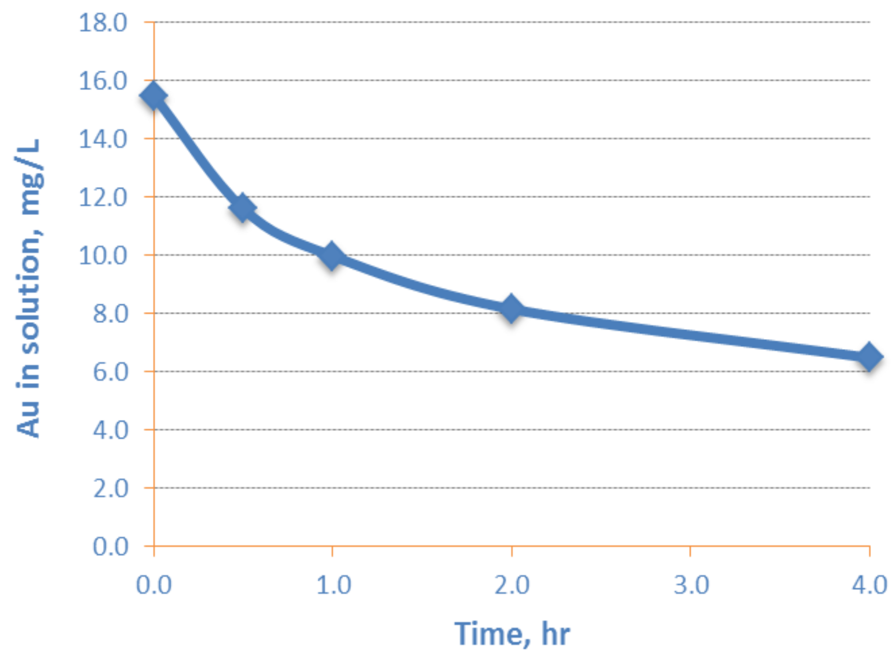
Time min	[Au] mg/L
0	38.70
30	24.60
96	15.82
180	12.08
240	10.26

Time min	[Ag] mg/L
0	56.1
30	48.1
96	42.7
180	39.1
240	37.0

Plot of Log (Δ[Me]c/[Me]s) against Log (t) for 4 hours (1 M Glycine; pH 10, T=25 °C; Activated Carbon 1.5 g/L) [13.2 kgAu/ton carbon in 4 hours]; [8.89 kgAg/ton carbon]

Metal recovery: Adsorption of metal glycinates onto activated carbon





Plot of Log (Δ[Me]c/[Me]s) against Log (t) for 4 hours (0.5 M Glycine; pH 10, Temp=25 °C; Activated Carbon 1.02 g/L) [6.7 kgAu/ton carbon in 4 hours]

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Conclusions

- Results show high potential for the use of alkaline amino acids at moderately elevated temperatures (40-60 °C) as alternative gold lixiviants.
- The presence of silver and Cu^{2+} ions enhance gold dissolution in the glycine-peroxide solutions.
- Gold leach rate from gold-silver (50% Ag) alloy is about 6 times higher than rate from pure gold.
- The silver leach rate (0.247 µmol/m2.s) is an order of magnitude higher than gold (0.012 µmol/m2.s).

Conclusions (Cont'd)

- Amino acids, or their salts, with a suitable oxidant (O_2, H_2O_2, Air) opens up a range of leaching options (ISL VL, HL) feasible at alkaline pH.
- Glycine, in particular, shows much promise due to bulk availability and low cost.
- Gold, silver and copper can be all be differentially leached using glycine, allowing sequential leaching with change in temperature and oxidant type/conc.
- Heating the leach solution between 40 and 60 °C was found to enhance the gold dissolution significantly in alkaline amino acid–peroxide solutions.

Conclusions (Cont'd)

- Gold dissolution increases by increasing amino acid concentration, peroxide and pH.
- The gold-glycinate complex was found to effectively load on activated carbon up to 13.2 g-Au/kg-carbon in 4 hours.
- Reagent suite is non-toxic (but leachate may not be).
- High stability of reagents and metal glycinate complexes.

Thank You!

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