Thiosemicarbazones are Good Spectrophotometric Reagent for Transition Metal Determination: A Review

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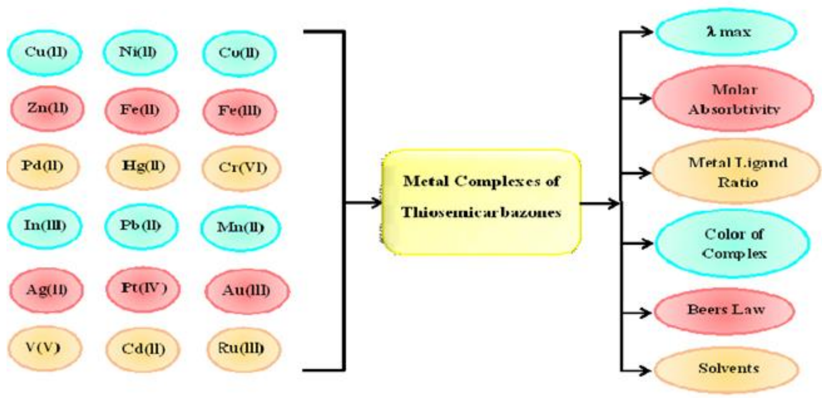
Abstract

In this communication, we reviewed metal complexes (Copper, Nickel, Cobalt, Iron, Zinc, Cadmium, Vanadium, Palladium, Indium, Chromium, Mercury, Lead, Silver, Manganese) of thiosemicarbazones and their analytical applications reported till 2021. The presented paper provides useful information about micro amount of transition metal determination in various samples using thiosemicarbazone as a complexing reagent by spectrophotometric methods. Substituted - thiosemicarbazones are important organic reagents and good chelating agents and have potential sites for the formation of complexes with various metal ions by bonding through azomethine *nitrogen* atom and thioketon sulphur atom. Some spectrophotometric complexing reagents gives higher absorbance with particular metal ions. Cu(II), Ni(II), and Co(II) metal makes higher complexes with this reagent.

Graphical Abstract



Keywords : ***Thiosemicarbazone, Transition metal complexes, Spectrophotometry, Analytical applications***

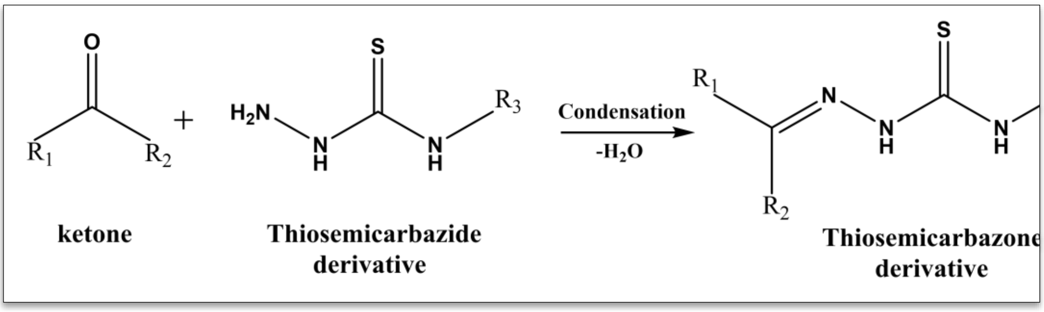
Abbreviations :
****N.R. = Not Reported***
****M:L = Metal Ligand Ratio***

Introduction

Thiosemicarbazones are used as a chelating ligand for the formation of metal complexes due to its variety of flexible donor sets of sulphur and nitrogen **[1].** They are known to coordinate with various metal ions to form coordination compounds in different modes **[2-6].** In last few years Thio and Phenyl Thiosemicarbazone have been a growing attention because of their bonding modes and present of amide, imine and thione group which makes them potentially polydentante ligand **[7].** Thiosemicarbazones have range of biological properties **[8-11]** antiretroviral **[12],** antimicrobial **[13,14],** anti-tubercular **[15-17],** anti-HIV, anti-fungal **[18-20],** antitrypanosomal **[21],** anti-amoebic **[22],** anti-malarial **[23],** anti-viral **[24],** antitumor**[25-31],** antibacterial **[32-36],** cytotoxicity **[24,37,102]** and anticancer agents **[38-41].** It has been seen that Cu(II), Ni(II), and Co(II) metal complexes of thiosemicarbazone dramatically increase the biological activities **[42].** It is condensed product of Thiosemicarbazide and aldehyde or ketone **[43-45].** Some transition metals are both micro nutrients as well as toxic element for living beings depending upon the concentration level **[46, 84].** This review discusses the analytical application of Thiosemicarbazone derivatives and their metal complexes. Even at low concentration, some transition metal and heavy metals are toxic when they enter into human body. Water, vegetables, milk, honey, vegetable oils, medicinal leaves are considered as major source of heavy metals **[47].** Also various metal ions play a significant role in human body **[65].** Human body is not capable to produce these metal ions itself **[73].** Due to lack of nutrition some diseases occur in absence of these ions **[48].** So it becomes important to identify trace quantity of heavy metal and transition metal ions in different sample such as water, biological, food, steel, industrial and soil, etc.

Literature survey has revealed that various analytical techniques **[49]** have been reported for the determination of metal ion which includes Atomic Absorption Spectrometry (AAS) **[50],** Inductively Coupled Plasma - Optical Emission Spectrometry (ICPOES) method, Inductive Coupled Plasma Mass Spectrometry (ICPMS) but spectrophotometric method is far more selective, simple, cheaper and rapid than among all these methods. Thus, there is an on-going need to develop a simple, selective, sensitive and inexpensive method for the determination of these heavy metal levels and continuous monitoring in food and water samples and analysis of environmental and biological samples. Hence, spectrophotometric method is one of the most commonly used techniques for routine analysis of metals, and also for the simultaneously determination of multiple elements **[51].** Spectrophotometric methods are preferred many times as they are cost effective, easy to handle, with a comparable sensitivity and accuracy, with good precision and because of this reason, several types of spectrophotometric methods for the determination of transition metal ions have been developed and there are many spectrophotometric organic complexing reagents **[52,53].**

❖ General Synthesis of Thiosemicarbazones



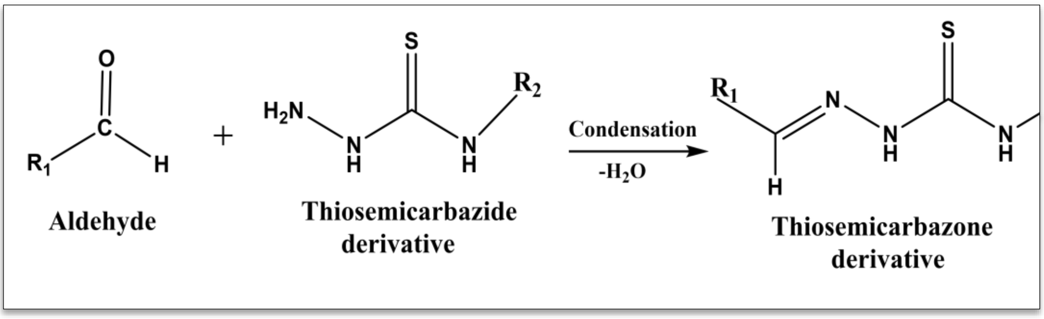


Table 1
Various complexing reagents for determination of copper(ll) by spectrophotometric methods

Sr. No.	Reagent Name	Metal Ion	M:L	Color of Complex	pH	λ_{max} (nm)	Solvent	Beer's law range µg /mL	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	2,6-DAPBPTSC	**Cu(ll)**	1:1	Yellowish orange	3	370	N.R.	0.63-6.30	0.84 $x10^4$	Food, milk, vegetable	**46**
2	PPT	**Cu(ll)**	1:1	Reddish brown	3-5.5	440	n-butanol	0.2-5.0	2.16 $x10^4$	Vegetable and Pharmaceutical samples	**65**
3	APPT	**Cu(ll)**	1:1	Reddish brown	3.0-5.5	440	n-butanol	0.2-5.0	2.16 $x10^4$	Vegetable and pharmaceutical samples	**61**
4	APS	**Cu(ll)**	1:2	Pale greenish yellow	5-7	355	N.R.	0.25-5.18	9.8 $x10^3$	Vegetable and alloys	**62**
5	APT	**Cu(ll)**	1:1	Pale greenish yellow	5-7	376	N.R.	0.25-2.54	2.6 $x10^3$	Vegetable and alloys	**62**
6	PAPTSC	**Cu(ll)**	N.R.	Yellow	8	341	N.R.	N.R.	1.1 $x10^4$	Copper wire	**63**
7	HnPBAPT	**Cu(ll)**	1:2	Yellowish orange	6.5	520	N.R.	Up to 10.16 Ppm	11.5 $x10^2$	Brass	**64**

8	PPT	**Cu(ll)**	1:1	Reddish brown	3.0-5.5	440	n-butanol	0.2-5.0	2.16 x10^4	Vegetable, pharmaceutical samples	**65**
9	PDPTSC	**Cu(ll)**	N.R.	Reddish brown	4.5	440	n-butanol	0.5-3.0	2.24 x10^4	Vegetable	**66**
10	DMABT	**Cu(ll)**	1:2	Yellowish	4.4-5.4	420	xylene, toluene	4.7	1.72 x10^4	Environmental samples and alloys	**58**
11	5-BSAT	**Cu(ll)**	1:1	Light greenish yellow	< 7	390	N.R.	0.31-6.35	1.08 x10^4	Grape leaves and aluminium based alloy	**59**

Copper Cu(ll) : In the human body copper is the third most abundant transition metal after Fe and Zn, and also it is essential trace element **[54-57].** In human body; liver and bones have the major concentration of copper. It is essential for human metabolism, however it becomes hazardous when excess amount is found. Some disease like "Jaundice" and "Wilson's disease" are resultant of excessive accumulation of copper in liver, kidney and brain **[58, 59].** It plays a significant role in cell respiration and in the formation of hemocyanin, which is an important respiratory protein, existed in the lymph of some animals belonging to Phyla Mollusca and Arthropods **[65].** There are many spectrophotomertry organic complexing reagents which can be used for the spectrophotometric determination of copper ion in food, green leafy vegetables, pharmaceutical samples, alloys and biological samples. Bis(thiosemicarbazone) complexes of copper shows the anticancer activity in vivo and in vitro **[60]** 2,6-diacetylpyridine bis-4-phenyl-3-Thiosemicarbazone (2,6-DAPBPTSC) **[14],** Pyridoxal-4-phenyl-3-thiosemicarbazone (PPT) **[65],** 2-acetylpyridine-4-phenyl-3-thiosemicarbazone (APPT) **[61],** 2- Acetylpyridine Semicarbazone (APS) & 2- Acetylpyridine Thiosemicarbazone (APT) **[62],** Pyruvic acid 4-phenyl-3-thiosemicarbazone (PAPTSC) **[63],** 2-Hydroxy-4-n-Propoxy-5-bromoacetophenone-4-Phenl-3-Thiosemicarbazone (HnPBAPT) **[64],** Pyridoxal-4-phenyl-3-thiosemicarbazone (PPT) **[65],** 3-hydroxy-5-(hydroxymethyl)-2-methyl-4-pyridine carboxaldehyde-4-phenyl-3-thiosemicarbazone (PDPTSC) **[66],** 4-[N,N(dimethyl)amino]benzaldehyde thiosemicarbazone (DMABT) **[58]** and 5-Bromo salicylaldehyde Thiosemicarbazone (5-BSAT) **[59]** are important complexing analytical reagents which are useful for determination of micro amounts of copper ion in different samples. DMABT and HnPBAPT forms complex in 1:2 (M:L) molar ratio, while other reagents forms in 1:1 (M:L) molar ratio. When reagents react with metal ion, some reagents give yellowish green colour and some reagents give reddish brown colour. In above table, all reagents give color in acidic pH except PAPTSC which gives color at pH 8.0. Complex shows maximum absorbance between 335 nm to 520 nm. Beer's law was obeyed in the particular range which is given in the table 1. Data of molar absorptivity shows that Cu(II)-PDPTSC has higher absorbance at 440 nm **[66]. C**hloroform, benzene, xylene, toluene, carbon tetrachloride and nitrobenzene are useful solvents for the spectrophotometric experiments.

Table 2
Various complexing reagents for determination of nickel(ll) by spectrophotometric methods

Sr.No.	Reagent Name	Metal ion	M:L	Color of Complex	pH	λ_{max} (nm)	Solvent	Beer's law µg /Ml	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	ECCT	**Ni(ll)**	1:1	Yellow	6	400	n-butanol	1.2-5.6	1.11 $x10^4$	Industrial influents and soil	**73**
2	PDT	**Ni(ll)**	1:2	Yellow	6	430	Isobutanol	0.35-3.53	1.6 $x10^4$	Leaves, alloys and soil	**69**
3	PPT	**Ni(ll)**	1:1	Reddish brown	4.0-6.0	430	n-butanol	0.5-5.0	1.92 $x10^4$	Medicinal leaves and soil	**73**
4	HnPBAPT	**Ni(ll)**	1:2	Yellowish orange	10	530	Chloroform	Up to 14.09 Ppm	6.71 $x10^2$	German Silver samples	**64**
5	PDPTSC	**Ni(ll)**	N.R.	Reddish brown	5	432	n-butanol	0.5-3.0	2.08 $x10^4$	Vegetables	**66**
6	KBAT	**Ni(ll)**	N.R.	Green	8-11	369	N.R.	0.30-2.34	1.55 $x10^4$	Steel, alloys, bio samples	**71**
7	HMBATSC	**Ni(ll)**	N.R.	Yellow	6.0	450	N.R.	0.05-3.42	N.R.	Alloy samples	**70**
8	PAPTSC	**Ni(ll)**	N.R.	Yellow	9	332	N.R.	5-25	1.52 $x10^4$	Pharmaceutical preparation	**63**
9	HMBATSC	**Ni(ll)**	N.R.	Yellow	6	474.5	N.R.	0.05-3.28	N.R.	Alloys and plants	**72**

Nickel Ni(ll) : Nickel(II) is found in small amounts in soils, plants and animal tissues. It is found relatively non-toxic and does not lead any serious human health hazard. The nickel deposited from nickel vessels in the human body causes no detectable hazard **[67,68].** The main source of nickel is iron factories, combustion of coal, diesel and residual oils, hydrogenation of oils, tobacco smoke, chemicals and catalysts. Steels in which nickel is a component are highly resistant to corrosion; due to its high melting point (1453°C) **[69].** In last few years several organic complexing reagent like N-ethyl-3-carbazolecarboxaldehyde-3-thiosemicarbazone(ECCT) **[73],** Pyridoxal-3-thiosemicarbazone (PDT) **[69],** 2-hydroxy-3-methoxy benzaldehyde thiosemicarbazone(HMBATSC) **[70],** 2-ketobutyric acid thiosemicarbazone (KBAT) **[71],** pyruvic acid 4-phenyl-3-thiosemicarbazone(PAPTSC) **[63],** 2-hydroxy-4-n-propoxy-5-bromoacetophenone(HnPBAPT) **[64],** 2-hydroxy-3-methoxy benzaldehyde thiosemicarbazone(HMBATSC**)** **[72],** Pyridoxal-4-phenyl-3-thiosemicarbazone(PPT) **[73],** 3-hydroxy-5-(hydroxymethyl)-2-methyl-4-Pyridine carboxaldehyde-4-phenyl-3-thiosemicarbazone (Pyridoxal-4-phenyl-3-thiosemicarbazone) (PDPTSC) **[66]** have reported for the determination of Micro amount of nickel in Industrial influents , soil, medicinal Leave, alloy, vegetable oil, water and plant. 1:1 and 1:2 (M:L) ratio was measured by job's and mole ratio method. These reagents give yellow, yellowish orange, reddish brown and green color complex under the pH range of 4 to 11. From data of spectrophotometric experiment it can be said that Ni(ll)-PDPTSC complex shows maximum absorbance at 432 nm. All complex gives maximum absorbance between 332 nm to 530 nm.

Table 3
Various complexing reagents for determination of cobalt(ll) by spectrophotometric methods

Sr. No.	Reagent Name	Metal ion	Color of Complex	pH	λ_{max} (nm)	Solvent	Beer's law µg /mL	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	PDPTSC	**Co(ll)**	Reddish brown	5	452	n-butanol	0.5-3.0	1.67 x10^4	Vegetables	**66**
2	PPT	**Co(ll)**	Reddish brown	N.R.	450	n-butanol	0.5-6.0	1.4 x10^4	Alloy steel and bio samples	**74**
3	HMBATSC	**Co(ll)**	Brown	6	485.5	N.R.	0.05-3.29	N.R.	Alloy, bio samples and plants	**72**
4	HMBATSC	**Co(ll)**	Brown	6.0	409.5	N.R.	0.05-3.53	N.R.	Synthetic mixtures and alloys	**75**
5	KBAT	**Co(ll)**	Pink	5-10	410	N.R.	0.33-2.65	1.03 x10^4	Steel, alloys and bio samples	**71**
6	HMBATSC	**Co(ll)**	Brown	6	460	N.R.	0.05-3.53	N.R.	Pharmaceutical Samples	**70**
7	PAPTSC	**Co(ll)**	Yellow	9	336	N.R.	5-25	1.62 x10^4	Pharmaceutical preparations	**63**

Cobalt Co(ll) : For biological organisms; cobalt is an essential micronutrient **[74].** Cobalt also plays a key role in the nitrogen fixation of plants by bacteria, also cobalt acts as a central metal ion in vitamin B12 **[74].** Bis(thiosemicarbazone) (BTSC) cobalt(III) complexes show activity against cancer **[61].** Analytical reagents like Pyridoxal-4-phenyl-3-thiosemicarbazone (PDPTSC) **[66],** Pyridoxal-4-phenyl-3-thiosemicarbozone(PPT) **[74],** 2-hydroxy-3-methoxy benzaldehyde thiosemicarbazone (HMBATSC) **[72],** 2-hydroxy-3-methoxy benzaldehyde thiosemicarbazone (HMBATSC) **[75],** 2-ketobutyric acid thiosemicarbazone (KBAT) **[71],** 2-hydroxy-3-methoxy benzaldehyde thiosemicarbazone (HMBATSC) **[70],** Pyruvic acid 4-phenyl-3-thiosemicarbazone (PAPTSC) **[63]** are reported by researchers for the determination of cobalt in micro level. Co(ll) reacts with PDPTSC, PPT, HMBATSC, HMBATSC, HMBATSC and give reddish brown or brown color, while Co(ll) reacts with KBAT and PAPTSC and give pink and yellow color respectively. Color formation occurs between the pH ranges of 5 to 10. Complex shows the maximum absorbance in the range of 336 nm to 485.5 nm. Co(ll)-HMBATSC complex shows the maximum absorbance. Beer's law was obeyed in their particular range which is shown in table 3. These methods are useful for the determination of cobalt in vegetable samples, alloys, steels, bio samples, synthetic mixture and pharmaceutical samples.

Table 4
Various complexing reagents for determination of zinc(ll) by spectrophotometric methods

Sr. No.	Reagent Name	Metal ion	M:L	Color of Complex	pH	λ_{max} (nm)	Solvent	Beer's law range µg /mL	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	PPT	**Zn(ll)**	1:1	Yellow	5.5	430	n-butanol	0.5-6.0	1.60 x10^4	Pharmaceutical and Biological Samples	**80**
2	ECCT	**Zn(ll)**	1:1	Yellow color	3.0-5.5	420	N.R.	0.4-6.0	1.55 x10^4	Food samples	**79**
3	5-BSAT	**Zn(ll)**	1:1	N.R.	6	381	N.R.	0.13-0.39	1.08 x10^4	Water samples	**81**
4	PAPTSC	**Zn(ll)**	N.R.	Yellow	6	361	N.R.	5-25	1.33 x10^4	pharmaceutical preparations	**63**
5	PDPTSC	**Zn(ll)**	N.R.	Yellow	5	438	n-butanol	0.5-3.0	1.74 x10^4	Vegetables	**66**
6	PDT	**Zn(ll)**	1:1	N.R.	5-7	430	N.R.	0.26-2.62	1.8 x10^4	Soil and vegetables	**82**
7	2-APT	**Zn(ll)**	1:1	N.R.	8-10	360	N.R.	0.25-2.56	2.9 x10^4	Soil and vegetables	**82**
8	MGBPT	**Zn(ll)**	1:1	Yellow	6.4	455	N.R.	0.2-4	2.1 x10^4	Potable Waters	**83**

Zinc Zn(ll) : Zinc act as a necessary nutrient in animals as well as in human beings **[76].** Approximately third part of the present zinc production goes into the galvanizing of ferrous metal, another third part is consumed in the brass alloys, while the remaining zinc is used into a number of chemical products **[77].** Zinc plays significant role in protein synthesis and cell division. Also it plays a crucial role in maintenance of cell membrane stability and function of immune system. However, zinc can be toxic when exposures exceed physiological needs. Short term exposure to concentrations of zinc in water between 1.0 and 2.5 mg/L leads to gastrointestinal distress, nausea and diarrhoea **[78].** Presence of zinc is also found in many foods, soil and in a number of pharmaceutical samples, which leads to environmental pollution **[79].** Pyridoxal-4-phenyl-3-thiosemicarbozone (PPT) **[80],** N-ethyl-3-carbazolecarboxaldehyde-3-thiosemicarbazone (ECCT) **[79],** 5-Bromosalicylaldehyde thiosemicarbazone (5-BSAT) **[81],** pyruvic acid 4-phenyl-3-thiosemicarbazone (PAPTSC) **[63]** and Pyridoxal-4-phenyl-3-thiosemicarbazone-(PDPTSC) **[66],** methylglyoxal bis(4-phenyl-3-thiosemicarbazone) (MGBPT) **[83]** are useful chromogenic reagents for the determination of zinc in food, water, pharmaceutical and vegetable samples. Zn(ll) forms 1:1 (M:L) molar ratio with PPT, ECCT, MGBPT and 5-BSAT. In the range of 3 to 6 pH it forms yellow coloured complex. Complexes show maximum absorbance between 361 nm to 481 nm. From the data of molar absorptivity Zn(II)-PDPTSC complex shows the maximum absorbance.

Table 5
Various complexing reagents for determination of cadmium(ll) by spectrophotometric methods

Sr. No.	Reagent Name	Metal Ion	M:L	Color of Complex	pH	λ_{max} (nm)	Solvent	Beer's law range µg /mL	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	2,6-DAPBPTSC	**Cd(II)**	1:1	Yellowish orange	9.5	390	N.R.	1.1-11.2	6.08 x10^4	Food and Water Samples	**84**
2	ECCT	**Cd(II)**	1:1	Yellowish orange	6	380	Kerosene	0.0-12	0.74 x10^4	Food and water samples	**47**
3	TTSC	**Cd(II)**	2:1	Green	9	422	N.R.	0.5-12	N.R.	Drinking water	**49**
4	BPMT	**Cd(II)**	1:1	Greenish yellow	8.0	400	N.R.	1.7-17.9	1.6 x10^4	Medicinal, Soil and vegetables	**85**

Cadmium Cd(ll) : cadmium is a lustrous, silver-white, ductile and highly malleable metal. Naturally a very large amount of cadmium is released into the environment, through weathering of rock, through forest fires and volcanoes. The rest of the cadmium is released through human activities, such as manufacturing processes, e-waste materials, and through sewage-sludge and fertilizers **[103].** It is easily absorbed by plants, through their root system and by leave **[104].** Human intake of cadmium takes place mainly through diet like liver, mushrooms, shellfish, mussels, cocoa powder and dried seaweed **[105].** One of the main reasons for cadmium accumulation in the body is the extensive use of tobacco. The outbreak of cadmium (II) poisoning occurred in Japan in the form of *itai itai* or *ouch ouch* disease **[107,108].** Symptoms include *fragileness* of bones **[109].** It is an extremely toxic metal, and the effects of acute cadmium poisoning are manifested in a variety of different symptoms including high blood pressure, kidney damage and destruction of red blood cells **[106].** 2, 6-Diacetylpyridine-bis-4-phenyl-3-thiosemicarbazone (2, 6-DAPBPTSC)**,** *N*-ethyl-3-carbazolecarbaxaldehyde-3-thiosemicarbazone (ECCT)**,** tetra-thiosemicarbazone (TTSC)**,** 2-benzoylpyridine-4-methyl-3-thiosemicarbazone (BPMT) are useful complexing analytical reagent for the determination of cadmium in medicines, soil, food and water sample in micro amount. Complex of TTSC with Cd(II) shows 1:2 M:L ratio where other reagent shows 1:1 M:L ratio. All complexing reagents give yellowish orange color complex except TTSC-Cd(ll). On the other hand TTSC-Cd(ll) complex gives higher absorbance at 9 pH.

Table 6
Various complexing reagents for determination of Iron(ll) by spectrophotometric methods

Sr. No.	Reagent Name	Metal Ion	Color of Complex	pH	λ max (nm)	Solvent	Beer's law range μg /mL	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	PAPTSC	**Fe(ll)**	Yellow	6.0	342	N.R.	5-25	1.71x10^{4}	Pharmaceutical preparations	**63**
2	PDPTSC	**Fe(ll)**	Yellow	5	424	n-butanol	0.5-3.0	1.88 x10^{4}	Vegetables	**66**
3	APT	**Fe(ll)**	Deep yellow with red tinge	4 - 7	370	N.R.	N.R.	0.17 x10^{4}	Soil, water, bio ayurvedic samples	**53**
4	APT	**Fe(lll)**	Deep yellow with red tinge	4 - 7	375	N.R.	N.R.	0.14 x10^{4}	Soil, water, bio ayurvedic sample	**53**
5	HMBATSC	**Fe(lll)**	Greenish yellow	6.0	432	N.R.	0.10-3.89	N.R.	Alloy samples	**70**

Iron Fe(ll) & Fe(lll) : The regular source of iron for human body is food. The iron deficiency is the most common cause of *anaemia*. Iron act as central metal ion in the blood protein which is known as hemoglobin [86]. To find micro amount of Fe(ll) and Fe(lll) metal ion in ayurvedic sample, pharmaceutical preparation, and vegetable sample there are some analytical reagents such as Pyruvic acid 4-phenyl-3-thiosemicarbazone (PAPTSC) **[63],** 3 hydroxy-5-(hydroxymethyl)-2-methyl-4-pyridine carboxaldehyde-4-phenyl-3 thiosemicarbazone (PDPTSC) **[66],** and 2-Acetylpyridine thiosemicarbazone (APT) **[53].** PAPTSC and PDPTSC react with Fe(ll) and gives yellow color. When APT reacts with Fe(II) and Fe(lll) give deep yellow color with red tinge. HMBATSC reacts with Fe(lll) and gives greenish yellow color. Fe complexes give color at 4 to 7 pH. In the range 342 nm to 424 nm, Fe complexes show maximum absorbance.

Table 7
Various complexing reagents for determination of Vanadium(v) by spectrophotometric methods

Sr. No.	Reagent Name	Metal Ion	Color of Complex	pH	λ_{max} (nm)	Beer's law range µg /mL	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	HMBATSC	**V(v)**	Green	6	430	0.05-4.07	N.R.	Biological samples	**70**
2	HMBATSC	**V(v)**	Green	6	434.5	0.05-4.07	N.R.	Synthetic mixtures and alloys	**75**
3	APT	**V(v)**	Yellow	3-7	360	N.R.	0.37 x10^4	Soil, water, bio ayurvedic samples	**53**

Vanadium V(V) : To determine vanadium at micro level; analytical reagents such as 2-hydroxy-3-methoxy benzaldehyde thiosemicarbazone (HMBATSC**) [70],** 2-hydroxy–3-methoxy benzaldehyde thiosemicarbazone (HMBATSC) **[75]** and 2-Acetylpyridine thiosemicarbazone (APT) **[53]** are useful. V(v)-HMBATSC and V(v)-HMBATSC gives Green color complex at 6 pH while V(v)-APT forms yellow colour complex between 3 to 7 pH. V(v)-HMBATSC, V(v)-HMBATSC and V(v)-APT show the maximum absorbance at 430 nm, 434.5 nm and 360 nm respectively. These spectrophotometry methods are useful for the determination of V(v) in synthetic mixture, alloys, soil, water and bio ayurvedic sample.

Table 8
Various complexing reagents for determination of Palladium Pd(ll) by spectrophotometric methods

Sr. No.	Reagent Name	Metal ion	M:L	Color of Complex	pH	λ_{max} (nm)	Solvent	Beer's law range µg /mL	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	PTSC	**Pd(ll)**	1:2	Pale yellow	2.0	420	N.R.	0.9-10.0	1.63 x10^4	Biological Samples	**87**
2	GBPT	**Pd(ll)**	1:1	Green	9.6	635	N.R.	N.R.	3.2 x10^3	Catalysts	**88**
3	PPT	**Pd(ll)**	1:1	Red	3.0	460	Benzene	0.4-6.4	2.2 x10^4	Synthetic mixture	**65**

Palladium Pd(ll) : In the platinum group metals, palladium has the lowest melting point and is the least dense. It plays a crucial role as catalytic converters. Palladium has wide range of applications both in chemical industry and in instrument making **[87].** It is also applicable in ornaments, production of watches and in blood sugar strips. Out of three, palladium is one of the most popular metals used to make white gold alloys. It is also found as *lindlar* catalyst, which is known as *Lindlar's* palladium [88]. Mononuclear salicylaldiminato(thiosemicarbazone) palladium(II) complexes show the activity as antimalarial and anticancer Agents **[89].** Pyridoxal Thiosemicarbazone (PTSC) **[87]** and Glyoxal Bis(4-phenyl-3-thiosemicarbazone (GBPT) **[88]** are analytical complexing reagent which are used for the determination of palladium(ll) in catalyst and biological samples. By mole ratio method it is found that GBPT and PTSC give 1:1 and 1:2 M:L ratio respectively. Pd(ll)-PTSC and Pd(ll)-GBPT give pale yellow and green colour at 2.0 pH and 9.6 pH respectively. Complex shows maximum absorbance at 420 nm and 635 nm respectively which is shown in table 8.

Table 9
Various complexing reagents for determination of Gold(lll) by spectrophotometric methods

Sr.No.	**Reagent Name**	**Metal Ion**	**M:L**	**Color of Complex**	**Ph**	**λ_{max} (nm)**	**Beer's law range µg /mL**	**Molar Absorptivity L mol^{-1} cm^{-1}**	**Determination of Metal in Real Sample**	**Ref.**
1	HMBATSC	**Au(lll)**	1:1	Blue	6	385	0.49-8.37	1.2 $x10^4$	Environmental water samples	**99**
2	APT	**Au(lll)**	1:1	Yellowish brown	4.0-7.0	365	0.1-12.3	2.1 $x10^4$	Synthetic Mixtures	**98**

Gold Au(III) : Gold belongs to the elements that occur on the earth in very low amount. It is one of the most important noble metals due to its wide application in industry and economic activity **[118].** Analytical Reagents like HMBATSC (2-Hydroxy-3-Methoxy Benzaldehyde) **[99]** and APT (Anisaldehyde-4-pheny1-3-thiosemicarbazone) **[98]** are useful for the determination of gold in micro amount in various samples. These reagents form complexes in 1:1 M:L ratio. HMBATSC-Au(lll) gives blue color complex at pH 6 whereas APT-Au(lll) complex gives yellowish brown color at pH 4 to 7. HMBATSC-Au(lll) complex shows higher absorbance than APT-Au(lll) complex.

Table 10
Various complexing reagents for determination of other metals by spectrophotometric methods

Sr. No.	Reagent Name	Metal Ion	M:L	Color of Complex	pH	λ_{max} (nm)	Solvent	Beer's law range µg /mL	Molar Absorptivity L mol^{-1} cm^{-1}	Determination of Metal in Real Sample	Ref.
1	APT	**Hg(ll)**	1:2	Yellow	6	351	N.R.	0.24-2.40	5.4 x10^4	Soil, water, bio ayurvedic samples	**53**
2	ECCT	**Pb(ll)**	1:1	Orange	6.0	440	Kerosene	0.0-10.0	1.8 x10^4	Food and water samples	**47**
3	PDPTSC	**Mn(ll)**	N.R.	Pink	4.5	420	Chloroform	0.5-3.0	2.1 x10^4	Vegetables	**66**
4	PDPTSC	**Ag(ll)**	N.R.	Reddish brown	5	442	Chloroform	0.5-3.0	2.2 x10^4	Vegetables	**66**
5	HMBATSC	**Cr(VI)**	N.R.	Intense green	6	407	N.R.	0.14-3.44	N.R.	Synthetic mixtures	**97**
6	HMBATSC	**In (III)**	N.R.	Intense green	6	430	N.R.	0.13-3.41	N.R.	Synthetic mixtures	**97**
7	DEABT	**Pt(IV)**	1:2	Yellow	N.R.	405	N.R.	7.80	1.7 x10^4	Alloys and pharmaceutical Samples	**100**
8	HMBATC	**Ru(III)**	1:1	Dark brown	<7	375	N.R.	0.50-8.10	0.9 x10^4	Synthetic mixtures and water samples	**101**

Mercury Hg(ll) : Mercury can exist in several forms, and all forms are poisonous. The most common forms of mercury that occurs naturally in the environment is metallic mercury **[90,88].** Example of mercury poisoning is *"Minamata disease"* which leads to mental disturbance; a loss of balance, speech, sight and hearing difficulty, and finally coma or even death **[89].** Inorganic mercury has very high attraction towards protein sulfhydryl groups, and accumulates in the kidneys, while organic mercury has a greater affinity for the brain **[53].** There is an increasing need to develop the simple and selective analytical techniques that do not use complicate or expensive experimental equipment in the analysis of environmental and biological samples. Though, the spectrophotometric method still has the benefits of being simple and not requiring expensive or complicated test equipments. Due to this reason, various types of spectrophotometric methods for the determination of mercury have been developed**.** 2-Acetylpyridine thiosemicarbazone (APT) **[53]** reacts with Hg(ll) and gives yellow coloured complex. It forms complex in 1:2 M:L ratio at pH 6.0 and shows maximum absorbance at 351nm. This method is useful to find out mercury amount in soil, water and ayurvedic sample.

Lead Pb(ll) : Pb(II) is essential in all the heavy metals to consider in terms of food chain contamination because of its toxicity **[98,99].** The exposure of Pb(II) leads to skin allergy, cancer and even birth defects **[93,94].** The main sources of these element are combustion of fossil fuel, industrial emissions, and chemical colorants **[95].** Also it is absorbed by water and veggies, especially leafy vegetables absorbs higher amount of Pb(II) in their leaves **[96].** N-ethyl-3-carbazolecarbaxaldehyde-3-thiosemicarbazone (ECCT) [**47]** is useful analytical reagent for the determination of lead in food and water sample. When it reacts with Pb(ll) it gives orange colour at pH 6.0. Complex was extracted into kerosene and it shows maximum absorbance at 440 nm.

Ruthenium Ru(lII) : Ruthenium is present in minerals such as laureate, rutheniridosmine and ruthenosmiridium as well as chondrites and iron meteorites (10–4%) **[110].** Ruthenium is most effective hardener in high density alloys, it is widely used in electronic industries, it also acts as a versatile catalyst used for removal of NOx from air stream **[111].** Ruthenium compounds are also used as anticancer drug **[112]** and for iden tification of amino acids **[113],** iodine/iodide **[114],** vitamin A **[115]** and chlorophenaramine **[116].** Some ruthenium complexes are used for light absorption in dye-sensitized solar cells **[117].** 2-hydroxy-3-methoxy benzaldehyde thiosemicarbazone (HMBATC) **[101]** is reported for the determination of ruthenium in synthetic mixtures and water samples by spectrophotometric method. Ru(lII)-HMBATC complex shows dark brown color in acidic pH. By job’s method it is found that in 1:1 M:L ratio HMBATC forms complex with ruthenium. This complex shows higher absorbance at 375 nm.

Chromium Cr(VI) and Indium In(lll) : Hexavalent chromium compounds are carcinogens. Some researches claims that the damage is resultant of production of hydroxyl radicals during re-oxidation of pentavalent chromium by hydrogen peroxide molecules present in the cell. Chromic acid is soluble compound which is much weaker carcinogen **[97].** The appearance of Indium is a soft, silvery, white metal which looks like zinc. While, it’s chemical properties are similar to aluminium and gallium. Pure indium is considered to be toxic in its metalic form. In very small amounts, Indium is used in aluminium alloys which act as sacrificial anodes to prevent passivation of aluminium. It is also used in fusible alloys, solders and as a dopant for semiconductors **[97].** 2-hydroxy-3-methoxybenzaldehyde thiosemicarbazone (HMBATSC) **[97]** is analytical reagent which is useful to find out the amount of Cr(Vl) and In(lll) in synthetic mixture. Cr(Vl)-HMBATSC and In(lll)-HMBATSC shows intense green coloured complex at pH 6. These complexes give maximum absorbance at 407 nm and 430 nm respectively.

Other Transition and Inner Transition Metal [**Mn(ll), Ag(ll) and Pt(IV)**] **:** 3-hydroxy-5-(hydroxymethyl)-2-methyl-4-pyridine carboxaldehyde-4-phenyl-3-thiosemicarbazone (PDPTSC) **[66]** is analytical complexing reagent which is useful for the micro amount determination of Mn(ll) and Ag(ll) in vegetable sample. It gives pink and reddish brown color at pH 4.5 and 5 respectively. Complexes were extracted into chloroform and shows maximum absorbance at 420 nm and 442 nm respectively. 4-[N, N-(diethyl) amino] benzaldehyde thiosemicarbazone (DEABT) **[100]** is useful analytical reagent for the determination of platinum (lV) in alloys and pharmaceutical samples. DEABT-Pt(IV) complex gives yellow color with 1:2 M:L ratio. It shows maximum absorbance at 405 nm.

Conclusion

This mini review reveals that in recent years so many researchers were concentrated on the analytical applications of thiosemicarbazones and their metal complexes. All metal complexes of Thiosemicarazone show color complex between the 2 to 11 pH range. Metal ligand ratio was found by the Job's method as well as mole ratio method, in most cases it was found 1:1 or 1:2. From the data of Molar absorptivity of complexes we can say that in which Wavelength (UV radiation) sample get higher absorbance and shows the electron transitions. Different types of Polar and Non polar solvents are used for the experiment. Transition metal shows more complex formation rather than the inner transition metal.

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