# GOLD IS EARNED FROM THE PRODUCTION OF THAI GOLD LEAF

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Thai people like to cover sacred objects or things dear to them with gold leaf.. Statues of Buddha are sometimes covered with so many layers of gold leaf that they become formless figures, that can hardly be recognized. Portraits of beloved ancestors, statues of elephants and grave tombs are often covered with gold leaf. If one considers the number of Thai people and the popularity of the habit, the amount of gold involved could be considerable.

One leaflet of Thai gold leaf of about 4 $cm^2$ weighs approximately 1 mg and in 1990 this leaflet cost 1 Baht, or Rp 240 (conversion rate 2001). Therefore Thai gold leaf costs about Rp. 240.000 per gram. In the Netherlands 1 gram of gold leaf costs about NLG 180 or Rp. 800.000. The international price of ingot gold is approximately Rp. 89.000 per garm. It is obvious that the cost of gold leaf is primarily determined not by the price of gold, but by the labor involved in making gold leaf out of gold. Labor in Thailand is rather chep and the price of gold leaf therefore seems quite reasonable. Each leaflet of Thai gold leaf is sold wrapped in a separate piece of paper with a vague but impressive looking stamp on it with a picture of an elephant and some illegible Thai text. The cover paper also facilitates the application of the gold leaf on objects.

Having been responsible for the practical education in Instrumental Chemical Analysis at Utrecht University for many years, I am always interested in analysis problems that might be used by students in their training. During my visist to Bangkok in 1989, I picked up a few pieces of gold leaf that were blown of a statue due to the wind. I took those pieces with me to have them analyzed in our laboratory. A first glance the Thai gold leaf did not look any different from the gold leaf sold in The Netherlands. I was therefore unaware there was something wrong with it. I could not possibly suspect I had stumbled over a complicated chemical problems.

For the analysis of metals, atomic absorption spectrometry (AAS) is the most logical technique. For the analysis of the Thai gold leaf with AAS, it was necessary to dissolve it in aqua regia, a mixture of concentrated hydrochloric acid and nitric acid. It was strange that the sample took a very long time to dissolve. The standard from pure gold wire dissolved quite rapidly. From the analysis by AAS with a Varian SpectraAA 10 instrument, using an acetylene-air flame it became very clear that Thai gold leaf contains no gold what so ever. Real gold dissolves readily in mercury. Thai gold leaf floated on mercury, but did not show any interaction with the mercury. It was obvious that Thai gold leaf was no gold, but the question remained: what is it really?

The behavior of the Thai gold leaf material made us suspect that it was at least partially of organic origin. During the second destruction, perchloric acid was used to facilitate the destruction. Two leaflets of Thai gold leaf were dissolved in boiling nitric acid, and drops of perchloric acid were added until the sample was dissolved. By means of ICP-analysis with and ARL 34000 ICP (Applied Research Laboratories) with a 30 channel simultaneous spectrometer it wad established that the material contained a small amount of aluminium, but no other metals. By means of AAS-Analysis, using a reducing acetylene-nitrous oxide flame it was determined that the material contained approximately 2,5% w/w aluminium.

In General Infrated spectrometry (IR) is a good method for the analysis of organic materials. It was however impossible to make a transmission IR-spectrom, because the material transmitted very little IR-radition. Therefore it was decided to make a spectrum by means of the”Attenuated Total Reflection”technique. In this technique the materials is applied to a crystal with a very high refractive index. The infrared radiation coming out of the crystal penetrates the material slightly and week but characteristic absorption takes place. By making the radiation reflect against the material for many times, a usable reflection spectrum is obtained. This analysis was performed on a Perkin Elmer 1720-X FTIR infrated spectrometer. From the obtained spectrum it became clear that

Thai gold leaf contained amide and ester functions,which points to a mixture of polymers, polyester and polyamide, e.g. nylon, or a copolymer. Thai gold leaf obviously consists of plastic that was aluminized to obtain a metal luster.

The thickness of real gold leaf can be determined by simple calculation from the surface area, the weight of the gold leaf and specific gravity of gold. The calculated thickness of real gold leaf is found to be 0,16 µm. It turns out that the thickness of Thai gold leaf can be determined from the IR-spectrum. The transmission spectrum gave no information about the chemical structure, but it did show an interference pattern that originates from the repeated reflection against the front and back side of the leaflet (analogous to an interference filter). Maxima in the IR-spectrum occur whe n 2.n.d=kλ., where n is the refractive index of the material, d the thickness, k the order of the reflection and λ the wavelength of the radition. For the reflactive index the average was taken of the revlactive indices of polyester and of nylon as published in literture. Thai gold leaf is found to be approximately 1,4 µm thick or 8,7 times as thick as real gold leaf. The weight of Thai gold leaf per $cm^2$ thereby comes close to that of real gold leaf. The mechanical strength of Thai gold leaf is considerably higher that that of real gold leaf, and of course this facilitates the application of Thai gold leaf to objects.

The dye that gave the gold color remained unknown. Many objects covered with gold leaf are subjected to rain, especially during the rainy season in Thailand. Obviously the dye had to be insoluble in water, but it dissolves readily in acetone, methanol and tetrahydrofuran. By means of mass spectrometry with a JEOL 102A double focussing mass spectrometer it was ettempted to get more information about the dye(s).With this technique it is possible to get information about the molecular weight from extremely small amounts of material (order of magnitude $10^{-9}$ gram). If more material is available it is also possible to obtain information on the chemical structure. The dye sample was ionized by means of "Fast Atom Bombardment". In this technique a minute amount of sample is mixed with a viscous matric, for instance glycerol. Then ionization takes place by bombarding the matrix surface with accelerated atoms. The ions that are formed are analyzed by mass spectrometry. The dye in Thai gold leaf had a high surface activity, and it did not mix sufficiently with the matrix. Therefore the time available for the analysis became very short and only a very limited amount of analysis data could be obtained. The conclusion was that mass spectrometric analysis of the extracted dyes did not give any usable information because the amount of sample available was too small and / or the composition too complex. Further investigation was not possible at the time, due to insufficient sample material. It turned out be fairly easy to obtain more sample material. After a publication of preliminary results in the prestigious newspaper NRC-Handelsblad (Section Science & Education, July 18th, 1991) 22 readers reacted by sending us letters and samples of Thai gold leaf from all over Thailand. Fortunately many people also mentioned where they bought the gold leaf. We obtained in this way some 200 leaflets of Thai gold leaf. That may seem like a lot, however it is still no more than 0,2 gram. Since the dye is only a small fraction of the total weight, we still had only a very small amount of sample.

All samples were checked individually, in order to make sure all were of the same general composition. Fortunately this was found to be the case. We did not find any real gold leaf among the samples.

The dye was dissolved in methanol, separately for each individual sample. The solution obtained was colored reddish. An absorption spectrum in visible light, made with a Hitachi 2000 spectrophotometer showed two distinct absorption maxima at 445 and 555 nm. The extracts were then analyzed by HPLC with a reserved phase RP 18 colomn and UV-Vis detection (Pharmacia) at the two mentioned wavelengths. Mixtures of water and methanol were used as eluent. In order to get a better separation we used a gradient of 40 to 75% methanol. Initially we found some 7 color components. Later the separation was repeated with acetonitril-water and a gradient of 40 to 75% acetonitril. This separation was carried out at two different PH values, 5,30 and 2,24. The dye sample turned out to contain at least 28 components, of which three main components and the remainder minor or trace components. The supposedly pure fraction of the main components were collected from the HPLC. By doing so, we used an analytical HPLC instrument for preparative purposes. By repeated injection, small quantities of these components, dissolved in the HPLC eluent were collected. The eluent was removed by means of a vacuum centrifuge. The amount of dye was so small that no spectrum could be obtained from a spectrophotometer. It was however possible to obtain the molecular mass of two main components by means of mass spectrometry. A yellow dye with a molecular mass of 693 and a red dye with a molecular mass of 337. The amount of dye was too small to obtain any structural information. As mentioned above, the solubility of the dyes in some organic solvents is known. Although a long list of dyes[1] was checked for these data, no dye cold be found that fitted the discription.

In principles it is possible to obtain more information about the dyes. It would then be necessary to repeat the experiments on a much larger scale. From a scientific and didactic point of view that would not be very useful or interesting, therefore we decided to drop the investigation at this point. However two clear conclusions can be drawn fromthe investigation:

1. The composition of Thai gold leaf is such that a high tech company is needed to make it.
2. A lot of real gold is earned by the production of Thai gold leaf.

## REFERENCE

Green, F.J. 1990, The Sigma Aldrich Handbook of Stains, Dyes and Indicators, Aldrich Chemical Company, milwauke.