

# Dependence of some SAGD Operations Characteristics on Steam Zone Pressure

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## Abstract

*A number of operations characteristics of Steam Assisted Gravity Drainage (SAGD) projects, such as production rates of hydrogen sulphide and carbon dioxide, silica dissolution, and scale production are strong functions of steam zone pressure.*

*The present paper explores the pressure dependence of acid gas (CO<sub>2</sub> and H<sub>2</sub>S) production, acid gas quality, and the associated potential for the need to recover sulphur in commercial SAGD projects. Further aspects explored are silica production, carbonate scaling, and the formation of unusual scales in SAGD facilities, as a function of steam zone pressure.*

## Introduction

There has been considerable interest in the issue of SAGD steam zone pressure (or temperature) in recent months. The issue revolves around the range of pressures under which a given SAGD project might be operated, without serious adverse economic effects on the project. Chhina<sup>1</sup> is reported to have advocated the use of lower pressures in order to reduce steam-oil ratios (SOR), and therefore production costs. The issue has been further explored by Kisman<sup>2</sup>, who defines low pressure SAGD as involving “pressures below what steam/gas lift can accommodate, and above pressures where low-pressure consequences such as reduced oil rates and artificial lift difficulties affect the viability of SAGD operations”. One of Kisman’s conclusions was that operation at reasonably low pressures provides savings not only due to reduced SOR, but due to the smaller production well liners and tubulars that may be used, although he cautions that low pressure SAGD remains to be confirmed in field tests. The main issues in whose context low pressure SAGD has been explored are therefore oil production rate, SOR, and artificial lift.

This paper explores a number of aspects of the engineering chemistry of SAGD, which are also dependent on the pressure (i.e. temperature) of the steam zone. In the author’s experience, these aspects have had significant impacts on some field operations. The engineering chemistry considerations point to potential benefits of operating SAGD at low pressure. The benefits include a possibility for avoiding the need for sulphur recovery.

## Acid Gas Production

Acid gases, carbon dioxide and hydrogen sulphide, are produced in SAGD projects by a process called “aquathermolysis” by Hyne et al.<sup>3</sup>. Hydrogen sulphide is produced entirely from bitumen, by a high temperature solvolysis of aliphatic carbon-sulphur bonds in the maltene fraction. Carbon dioxide is thought in part to originate from the bitumen, as a result of decarboxylation reactions, and in part from the sand. While inorganic carbonates such as calcite and dolomite will not decompose thermally at SAGD conditions, formation of acids from thermal decomposition of other minerals in the sand will provide a pathway for carbon dioxide production.

Production of the acid gases, on a basis of bitumen produced, is low. Hyne et. al. report production rates of up to 75 liters of H<sub>2</sub>S and up to 10,000 liters of CO<sub>2</sub> per m<sup>3</sup> of Athabasca bitumen steamed in an autoclave at 240<sup>0</sup>C. The present author’s experience in the field confirms this general order of magnitude, although production rates are generally less than the figures quoted. Nevertheless, these production rates, in a 10,000 m<sup>3</sup>/day bitumen project, are sufficient to trigger Alberta’s sulphur recovery requirements.

The temperature dependence of the production of hydrogen sulphide and carbon dioxide from Athabasca bitumen has not been studied in detail. From work by Strausz et.al<sup>4</sup>, an Arrhenius activation energy of 56225 kJ/mole (13451 cal/mole) for hydrogen sulphide is available. For carbon dioxide, an activation energy of 18110 kJ/mole is reported. For the present purpose these values are used to illustrate the expected temperature dependence of acid gas production, with the assumption that the production is not complete at 240<sup>0</sup>C or is subject to competing reactions.

The temperature dependence of gas production so derived, for 75 liters H<sub>2</sub>S and 5,000 liters of CO<sub>2</sub> per m<sup>3</sup> of Athabasca bitumen at 240<sup>0</sup>C, is shown in Figures 1 and 2. The calculations make allowance for the temperature dependent solubilities of both gases in water, as described by Thimm<sup>5</sup>. Clearly, there is a significant increase of hydrogen sulphide production with temperature, as expected from the literature. The rate of increase of carbon dioxide production is somewhat less pronounced, although absolute production rates are larger than those for hydrogen sulphide.

### **Acid Gas Quality**

Acid gas quality, derived from the previously calculated production data, will in almost every case be poor, with attendant challenges to sulphur recovery efficiency. As shown in Figure 3, the hydrogen sulphide content of the acid gas reaches only about 3% in the high steam pressure range. Again, the reader is cautioned that Figure 3 needs to be revised on a site-specific basis. In general, however, some manner of separating carbon dioxide and hydrogen sulphide may be called for.

In terms of hydrogen sulphide content, the acid gas from SAGD operations, even that from a high temperature steam zone, more closely resembles a Claus Process tail gas than it does a feed gas. It therefore seems likely that sulphur recovery at a reasonable

efficiency will require at least a hindered amine process to separate hydrogen sulphide from carbon dioxide.

### **Dissolution of Silica**

As is well known from empirical observation, high steam pressures tend to cause the dissolution of silica minerals in the steam zone and their production with produced water. In addition to silica deposition in facilities if not removed, the silica becomes available for reaction with other components of the produced water to form unusual silicate scales.

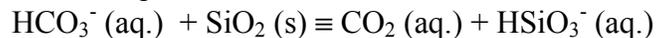
The thermodynamic tendency of silica to dissolve may be conveniently shown as a function of temperature by utilizing the SOLMINEQ program. This program permits calculation of a scaling index for a variety of minerals, including various silicas. A positive scaling index should be taken as a tendency to scale. Conversely, a negative index indicates a tendency for dissolution. An assumed water chemistry, fairly typical of that found in the upper McMurray zone of Alberta, is used to estimate temperature effects. The approximate composition is given in Table 1.

***Table 1: Test Composition of McMurray Produced Water***

| ANALYTE          | CONCENTRATION, mg/L | ANALYTE                       | CONCENTRATION, mg/L |
|------------------|---------------------|-------------------------------|---------------------|
| Na <sup>+</sup>  | 2200-2300           | Cl <sup>-</sup>               | 2820-2850           |
| K <sup>+</sup>   | 45                  | SO <sub>4</sub> <sup>2-</sup> | 5-250               |
| Mg <sup>2+</sup> | 36                  | HCO <sub>3</sub> <sup>-</sup> | 1200                |
| Ca <sup>2+</sup> | 0.1                 | Silica                        | 50                  |
| Ba <sup>2+</sup> | 2                   |                               |                     |

Figure 4 shows that all forms of silica, including the quartz sand, will show a small tendency to dissolve. The tendency increases with temperature. High steam pressure will therefore increase the tendency towards silica production, and will influence the removal needs.

In this respect, it is worth mentioning that steam quality also has an effect on silica dissolution. While it is widely known that high pH in the liquid steam phase will increase the tendency of silica to be produced, this property in itself may not be all that is necessary. High alkalinity, at near-neutral pH, will also cause an increase in silica production, by virtue of the equilibrium



On the other hand, high alkalinity of the source water will cause a high pH of the water mist phase, owing to decomposition of the bicarbonate to carbonate. Injection of this phase with the steam (i.e. less than 100% quality) will thus increase production of silica, owing to high pH. Whether the above equilibrium lies sufficiently to the right to form silicate, or whether the high pH of the mist phase is responsible, is presently unclear.

However, it is in accord with the author's observations in SAGD pilots that injection of steam at less than 100% quality significantly increases the silica production.

### **Calcium and Magnesium Silicates**

While silica is brought into solution by high steam temperature, it is also available for the formation of calcium and magnesium silicates. The common silicates of calcium and magnesium will tend to scale with higher temperature. Figures 5 and 6 show the tendency of scaling indices to rise with temperature. The worst potential actors are likely to be talc and tremolite. The author has observed both of these minerals in SAGD wells and facilities.

### **Other Minerals**

As is well known, carbonate minerals such as calcite and dolomite tend to scale in facilities with higher temperature. The same scaling tendency is predicted for producing wells (Figure 7). The formation of barite, on the other hand, is favoured by lower temperatures (Figure 8). Since barite formation is a necessary condition for the occurrence of naturally occurring radioactive materials (NORM's) in scales, it seems unlikely that a project in Athabasca will ever experience problems with NORM's. Projects elsewhere in Western Canada may be more prone to this problem. The remedy for this problem would be an increase in steam temperature.

### **Discussion**

From the perspective of sulphur recovery, each project needs to be evaluated on its own merits, because it is not appropriate to quantitatively assume the production rates of hydrogen sulphide and carbon dioxide underlying the calculations shown here. Bitumen from each deposit, or even from different locations within the same general deposit, will produce acid gases at rates that depend on bitumen composition and on the reservoir sands. This work merely shows the exponential trends for acid gas production.

However, it is worth noting that the hydrogen sulphide production virtually vanishes below 200<sup>0</sup>C. Hence it may be possible to avoid sulphur recovery altogether where low pressure SAGD is a viable option.

Experience suggests that sulphur production (as hydrogen sulphide) in SAGD will vary with a standard deviation of approximately 25% of the mean. Thus the first to the 99<sup>th</sup> percentile range from 0.25 to 1.75 times the mean. Sulphur recovery guidelines in Alberta have been developed for sour gas, where the composition of inlet streams is much less variable. This fact, plus the poor acid gas quality impose some serious engineering challenges for sulphur recovery in SAGD projects.

Acid gas quality in SAGD is almost certain to be poor in Athabasca. The conversion efficiencies of hydrogen sulphide to sulphur are strongly dependent on hydrogen sulphide content of the acid gas, at least in the Claus Process. The low acid gas quality therefore

becomes a serious issue. It may be necessary, in some cases, to separate hydrogen sulphide from carbon dioxide, in order to achieve regulatory targets for sulphur recovery. Economics of a SAGD project will therefore have to weigh the impact of additional capital costs and operational costs for sulphur recovery, versus the reduced oil rate of low pressure SAGD.

If the mean sulphur production can be kept below 0.5 tonnes/day, the problems of sulphur recovery will be avoided, at least for Athabasca. Low pressure SAGD is therefore an option worthy of consideration.

Scaling in the formation near the wellbore, in the well production tubing and in the facilities is also an issue in SAGD. Common carbonate scales are well known to be favoured by higher temperatures. The newer aspect is the potential for encountering scales that have rarely, if ever, been encountered in conventional oil projects. The increased tendency to dissolve silica in the formation is accompanied by an increased tendency to form calcium and magnesium silicates as steam pressure is increased. Such scales have been observed in thermal projects.

An interesting observation from the chemical simulations is that the production of carbon dioxide, at least while in intimate contact with the water phase, protects against scaling of magnesium and calcium silicates. The above chemical equilibrium between bicarbonate and silica also suggests that it may protect against the dissolution of silica by a mass law effect.

### **Other Considerations**

Another factor that needs to be taken into account is the asymptotic behaviour of Henry's Law as the critical point of water is approached<sup>5</sup>. Although SAGD operations temperatures are well below the critical point of water, the asymptotic behaviour of Henry's Law already governs the behaviour of gas solubility at the SAGD temperatures.

Assuming that a gas cap is non-existent or is not depressurized, the solubility of gas at the lower SAGD temperature considered may lead to inefficient removal of gas from the steam zone via steam condensate, thus leaving gases to accumulate in the steam zone. The implications of this effect on productivity have been partially studied by Kisman and Yeung<sup>6</sup>, in a simulation study where the effects of solution gas ratio and volatility were considered. Kisman & Yeung found that a moderate amount of gas in the steam zone appears to be beneficial for SAGD performance, but there were indications of reduced performance with increased solution gas volatility. The situation with the presence of large amounts of gases that are not solution gas and which are essentially insoluble in bitumen has not been considered. While the data in this paper indicate that less carbon dioxide will be formed at reduced steam zone pressure, the solubility and thus removal efficiency of the gas is also reduced. The quantitative treatment of this potential effect is beyond the scope of this paper.

Inspection of the figures in this paper suggests that most of the potential benefits of lower pressure should be reached at a temperature of about 180°C, corresponding to about 1000 kPa steam zone pressure in Athabasca. This result is derived on the basis that hydrogen sulphide production from Athabasca bitumen is negligible below this temperature. Further, given that it will be almost impossible to achieve conditions at which dissolution of silica minerals are completely suppressed, one may use a scaling index as  $-0.5$  as a tolerable value. This will also be accomplished at 1000 kPa or less. The optimal pressure in any project will of course include other considerations such as predicted SOR and oil production rates, and the requirements for artificial lift.

## Conclusions

1. For the most part, the engineering chemistry aspects of SAGD tend to favour low pressure SAGD. Only in unusual cases, where NORM's are involved, or where an improvement in acid gas quality is desired, might a higher pressure be favourable.
2. Sulphur recovery from SAGD projects in Athabasca is problematic for reasons of relatively high variability in hydrogen sulphide production rates, and from very poor quality of acid gas. However, at lower SAGD pressures it may be possible to avoid sulphur recovery altogether.
3. Determination of the optimal pressure for SAGD is complicated by the effects of steam pressure on solubility of gases in water, which constitutes the main removal mechanism for gases from the steam zone. Low pressure SAGD therefore requires demonstration in the field, for this as well as other reasons.

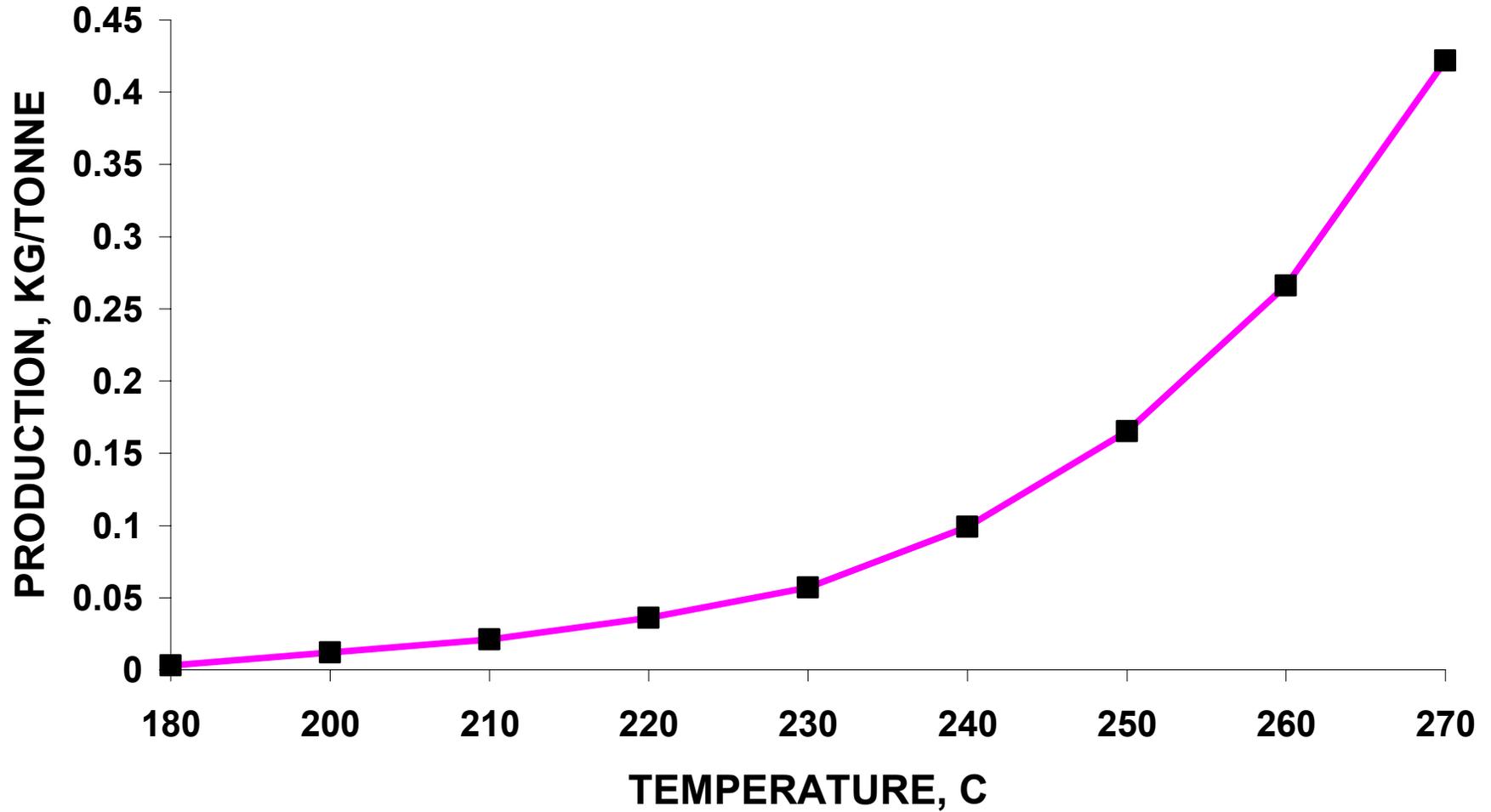
## Acknowledgements

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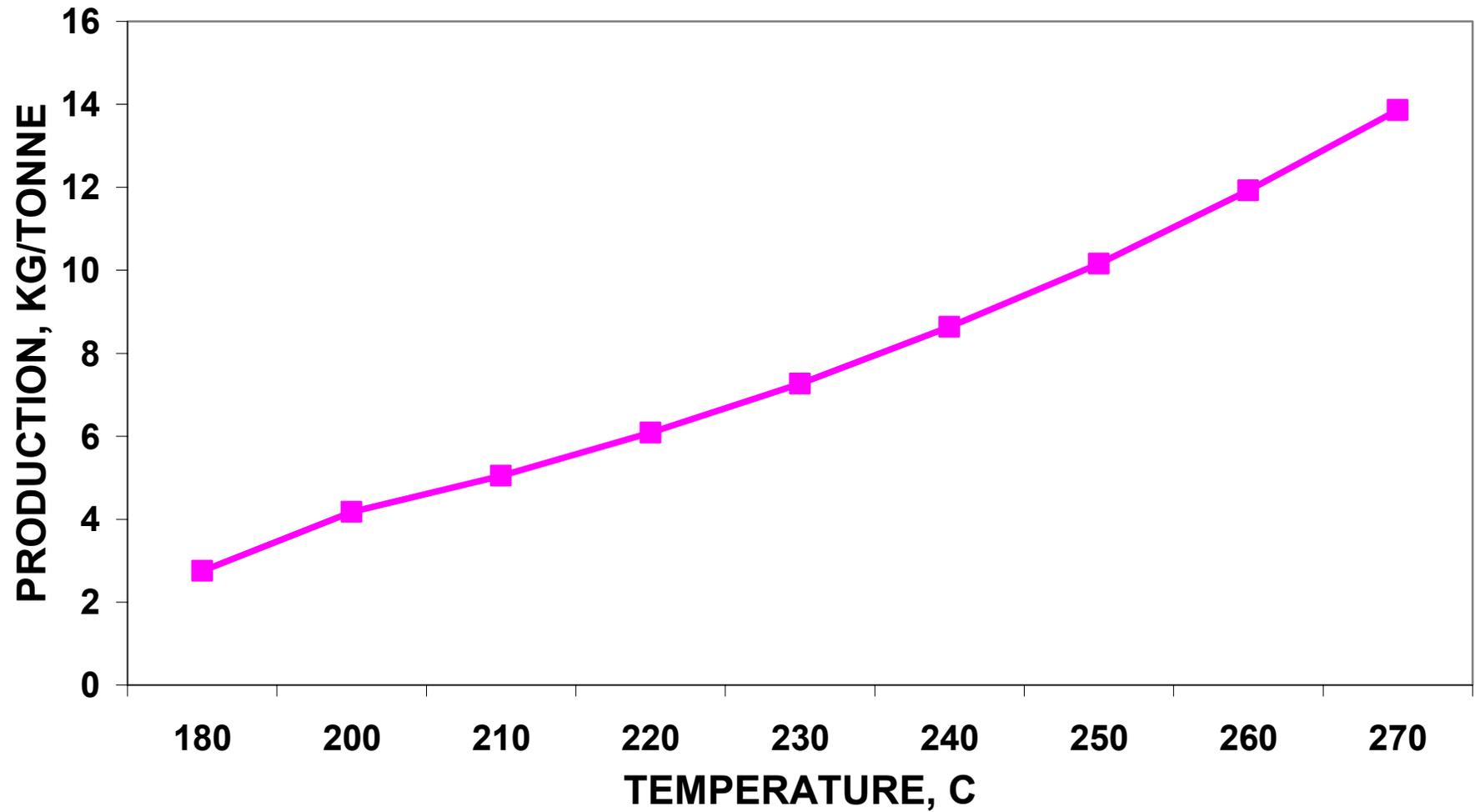
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**Fig. 1: HYDROGEN SULPHIDE PRODUCTION AS A FUNCTION OF TEMPERATURE**



**Fig. 2: CARBON DIOXIDE PRODUCTION AS A FUNCTION OF TEMPERATURE**



**Fig. 3: HYDROGEN SULPHIDE IN ACID GAS, PPM**

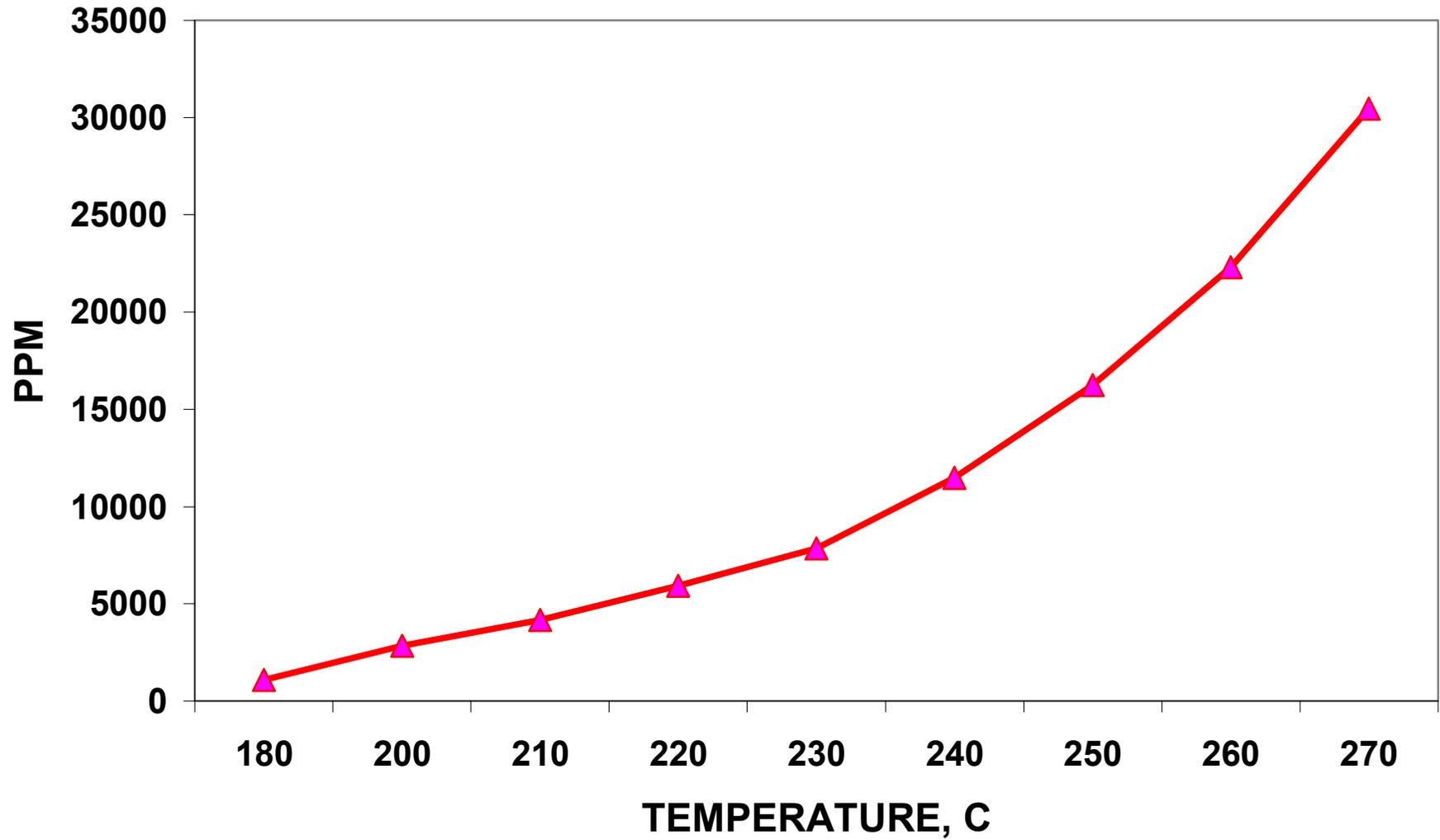
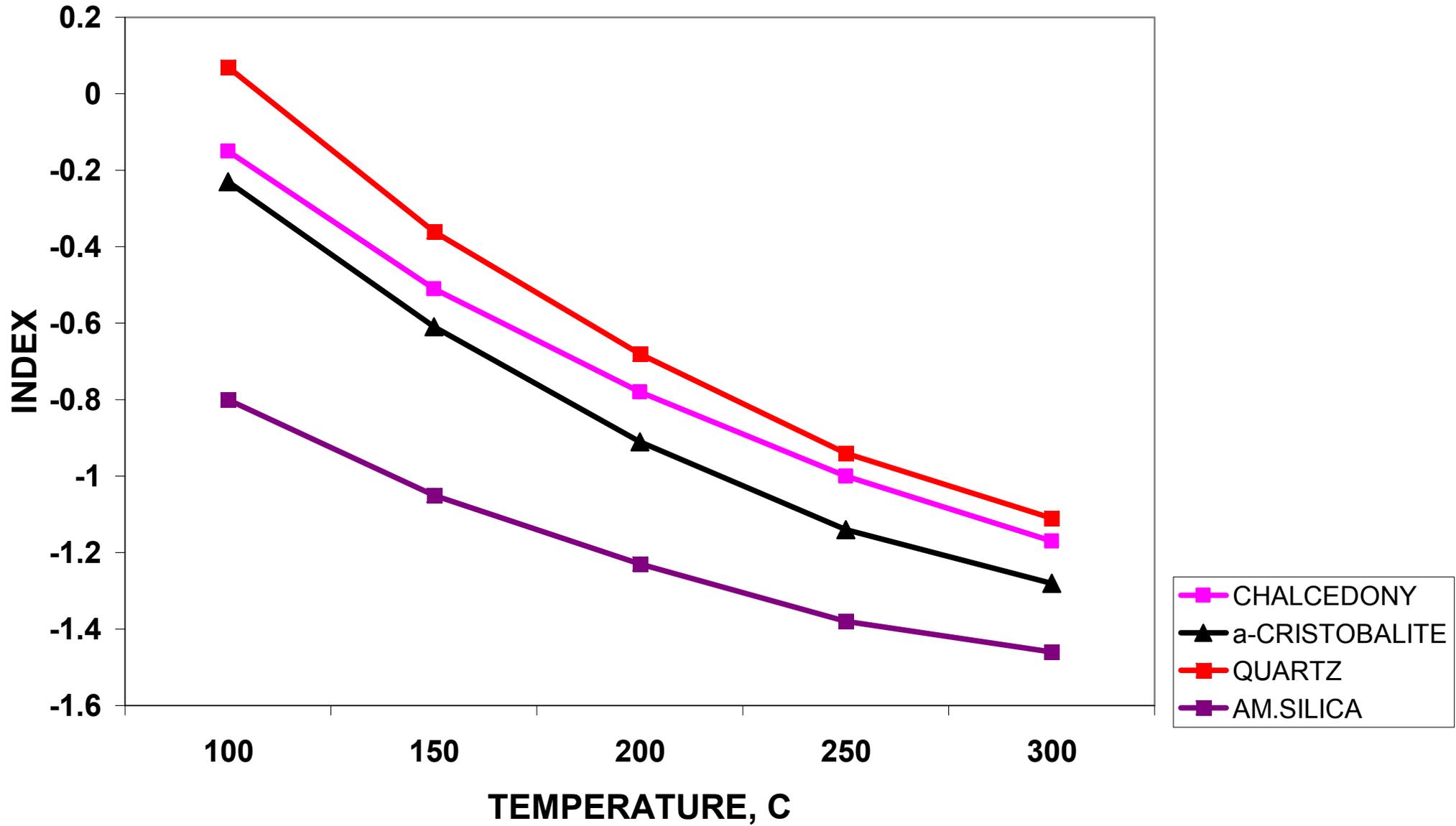
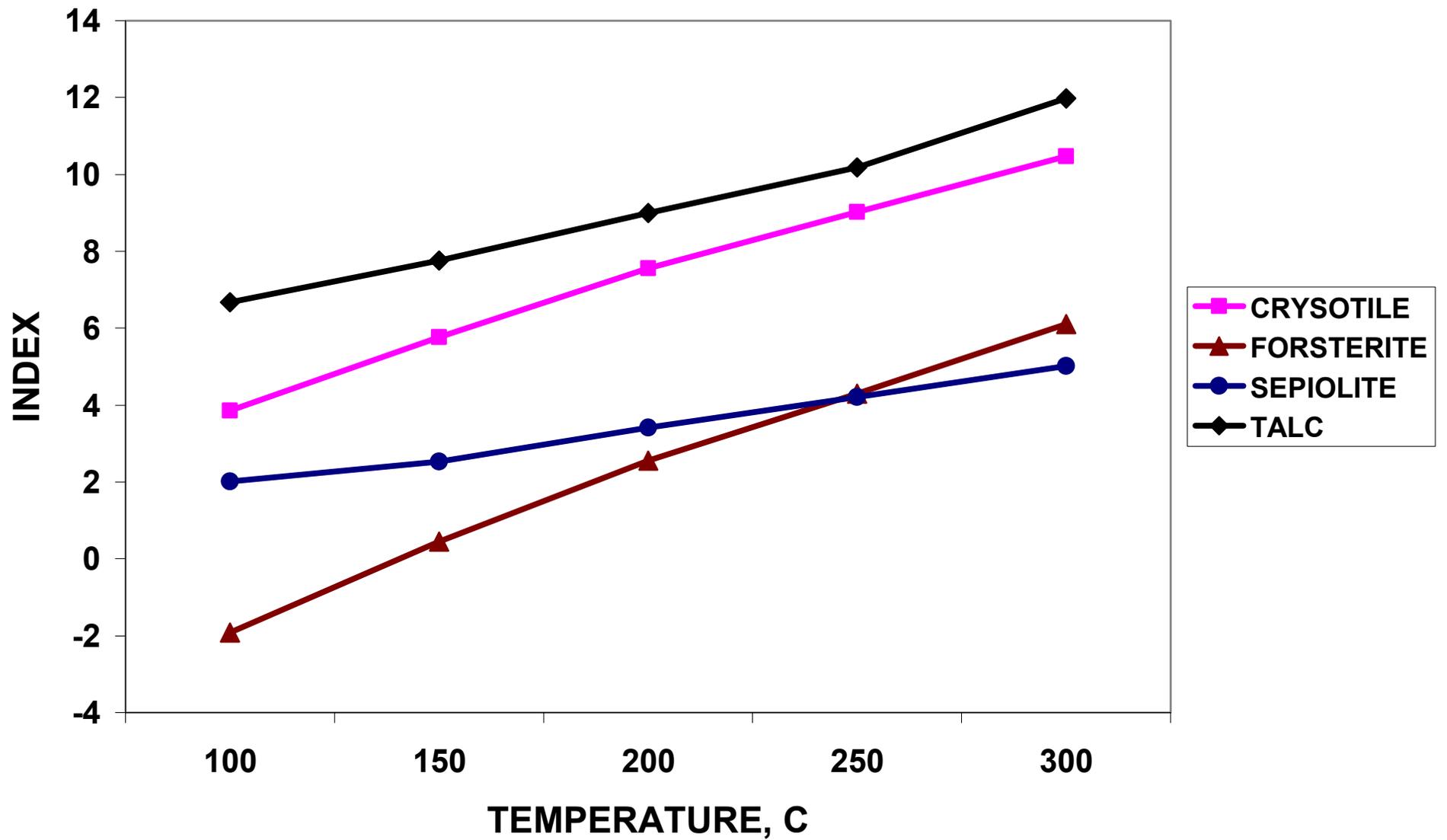


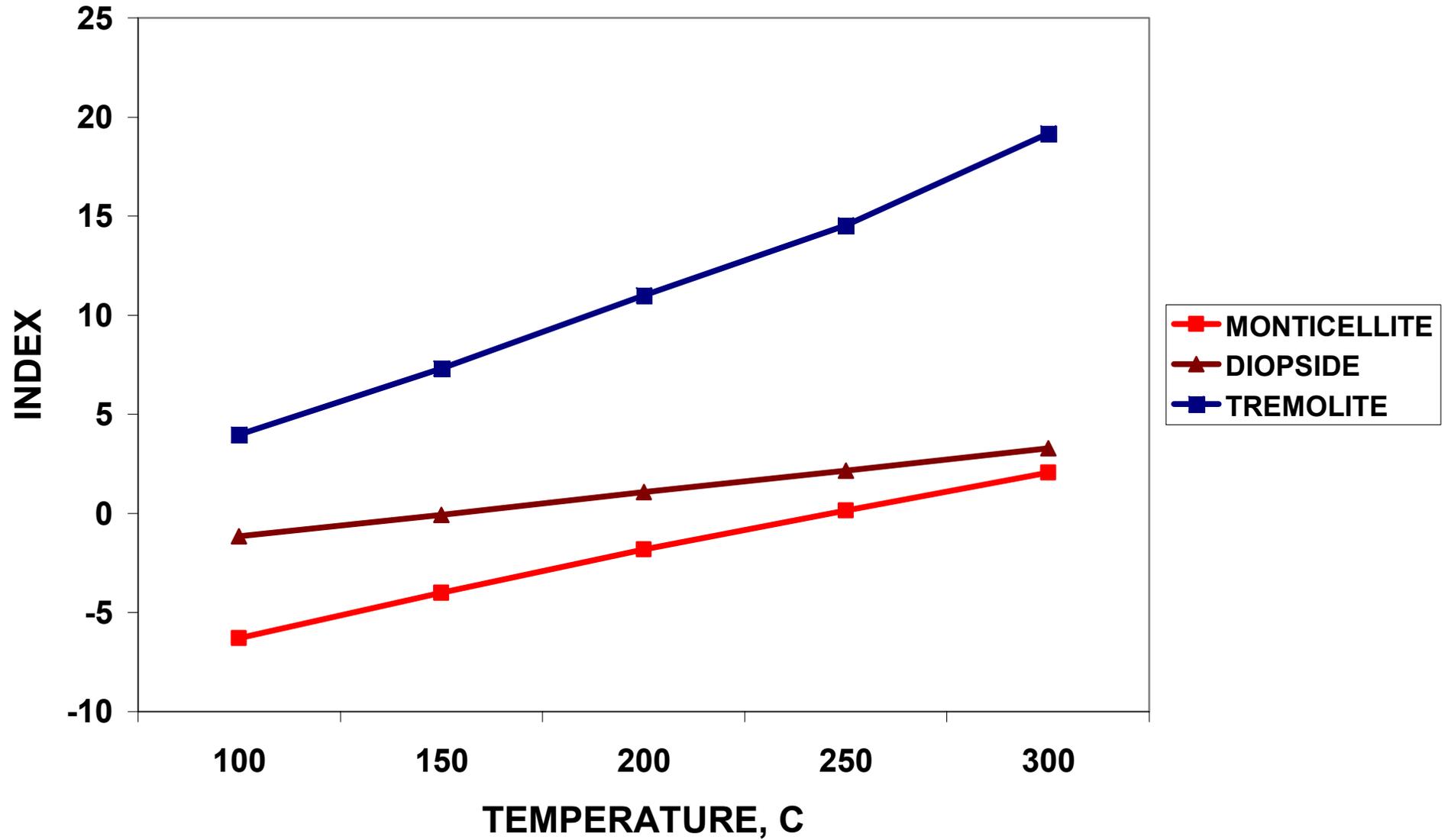
Fig. 4: SCALING INDICES OF SILICA



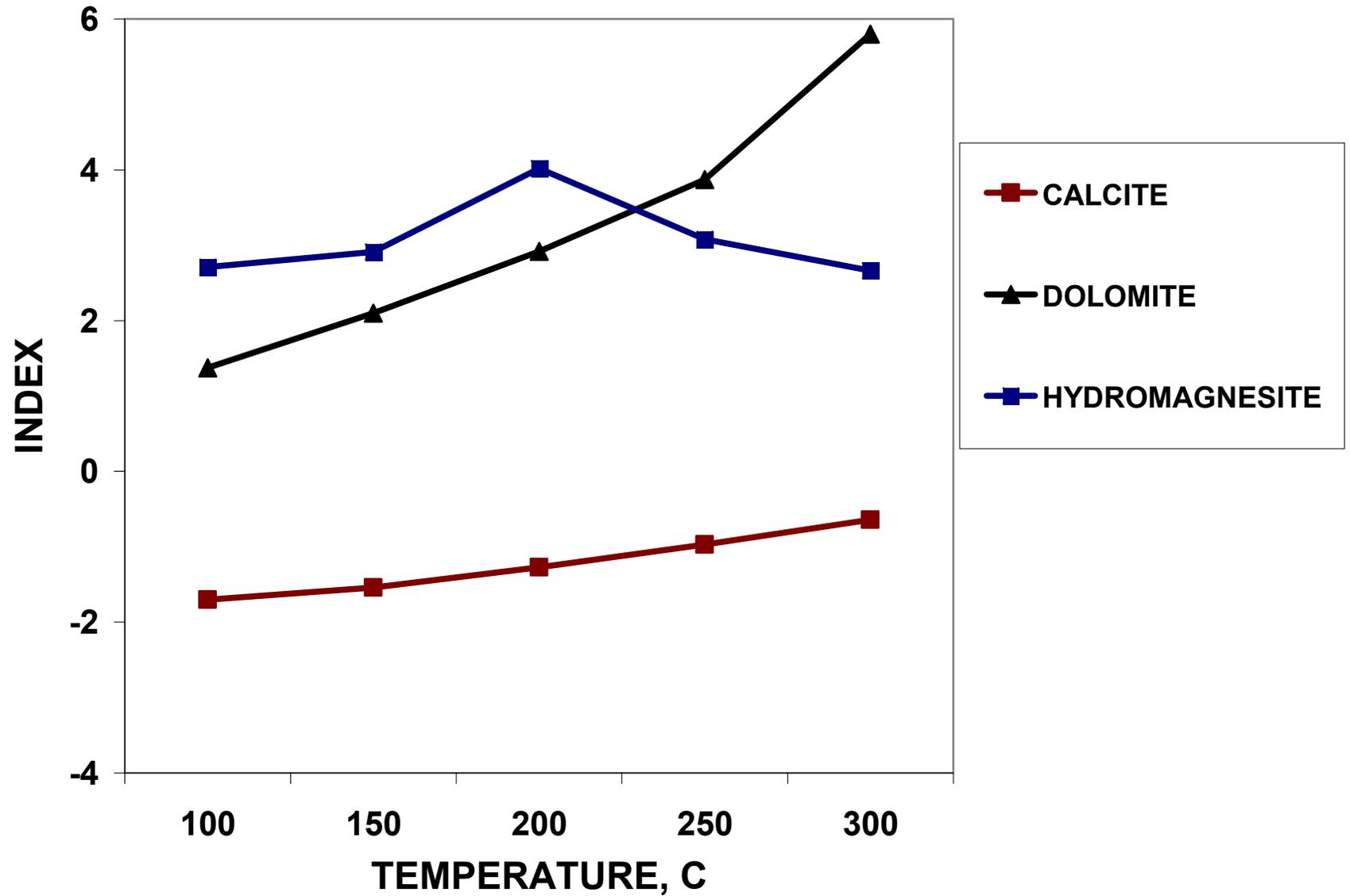
**Fig. 5: SCALING INDICES OF Mg SILICATES**



**Fig. 6: SCALING INDICES OF Ca SILICATES**



**Fig. 7: SCALING INDICES OF CARBONATES**



**Fig. 8: BARITE SCALING INDICES**

