# Flow Sensors of Heat Meters for Thermal Solar Systems

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## Introduction

For measurements of thermal energy, produced by thermal solar systems, heat meters, installed in collector circuits of solar systems, must be qualified for the most used propylene glycol-water-mixtures as heat conveying liquid. In the project, sponsored by the "Deutsche Bundesstiftung Umwelt (DBU)" and the heat meter industry, the accuracy of several types of flow sensors at nominal flow rates between 0.6 $m^3/h$ and 1.5 $m^3/h$ had been investigated using propylene glycol-water-mixtures.

## Experimental Set-up

For a given propylene glycol-water-mixture the measurements of the calibration factors (**CF**) of the flow meters as a function of flow rate and temperature were carried out by comparison with two electromagnetic flow sensors, alternatively used corresponding to the actual flow rate. These reference meters were calibrated simultaneously with the static gravimetric method operating in the flying start-finish mode. It was possible to investigate in the test line up to three flow meters with pipe diameters of 15 mm, 20 mm or 32 mm. The temperature of the heat conveying liquid could be adjusted from –10 °C up to 80 °C and the flow rate from 15 l/h up to 3000 l/h. The weighing reservoir of the test facility has a volume of 250 l, and so, a period of about 5 minutes was needed for filling the reservoir at the highest flow rate of 3000 l/h. Therefore the influences of time errors (1 ms) and time uncertainties (2 ms), generated by the diverter, may be neglected (combined relative uncertainty $< 1 \bullet 10^{-5}$). The combined relative uncertainties of volume measurements caused by the gravimetric test facility amounted to (without evaporation losses) less than $5 \bullet 10^{-4}$.

## Measurements

Most of the experiments were conducted using a glycol-water-mixture which consisted of 50 vol.-% TYFOCOR L (96 vol.-% propylene glycol and 4 vol.-% additives) and 50 vol.-% water. This is the highest concentration of propylene glycol used in thermal solar systems, because the concentrations of propylene glycol vary typically between 40 vol.-% and 50 vol.-%. But, for testing the influence of the glycol concentration on the CF of the flow meters mixtures with 25 vol.-% TYFOCOR L or 72 vol.-% TYFOCOR L were also sometimes used.
To compare the individual performance of a device against its type performance usually at least three meters of the same meter type were tested. All measurements were repeated several times under the same conditions to determine random uncertainties.

## Results

The following types of flow sensors were investigated:
1. turbine meters
2. electromagnetic flow sensors
3. ultrasonic flow sensors
4. electronic vane-wheel flow meters (single-jet and multi-jet)

Because of their poor performance turbine meters, often used by a manufacturer of heat meters of thermal solar systems, were only proved with the heat conveying liquid water at a temperature of 20 °C (figure 1).

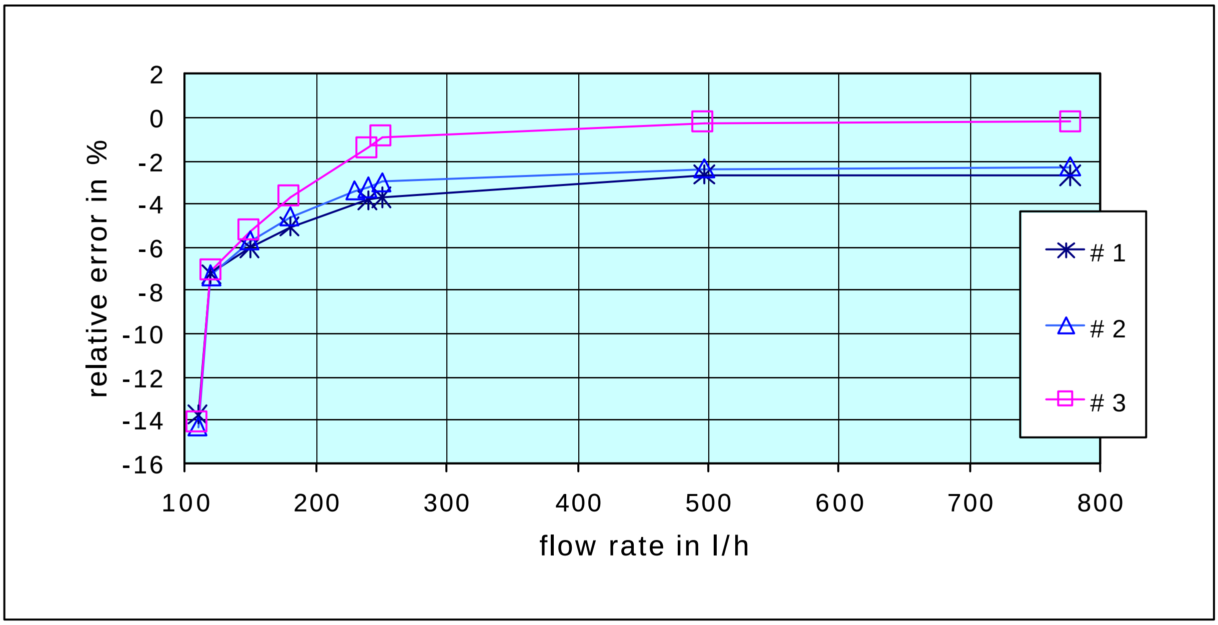


**Figure 1**: Relative error curves of VTS turbine meters at 20 °C (heat conveying liquid: water)

The electromagnetic flow sensors (figures 2 and 3) are too expensive for small thermal solar systems.

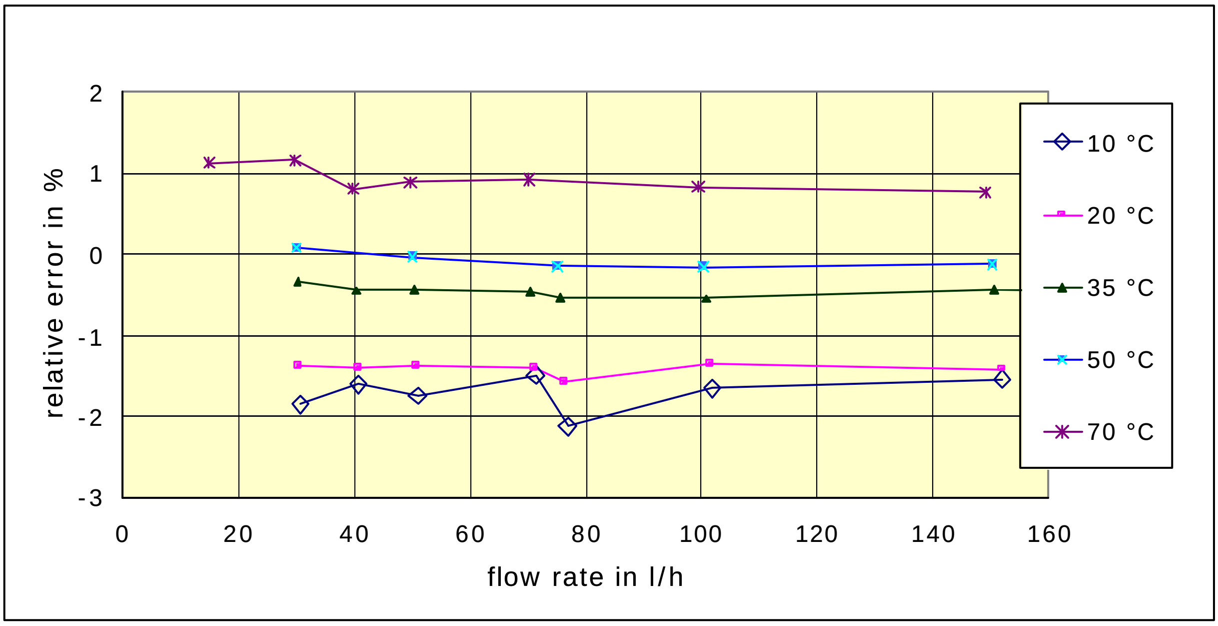


**Figure 2**: Relative error curves of IFS 5000 electromagnetic flow sensors with nominal width DN 2,5 (heat conveying liquid: propylene glycol-water-mixture)

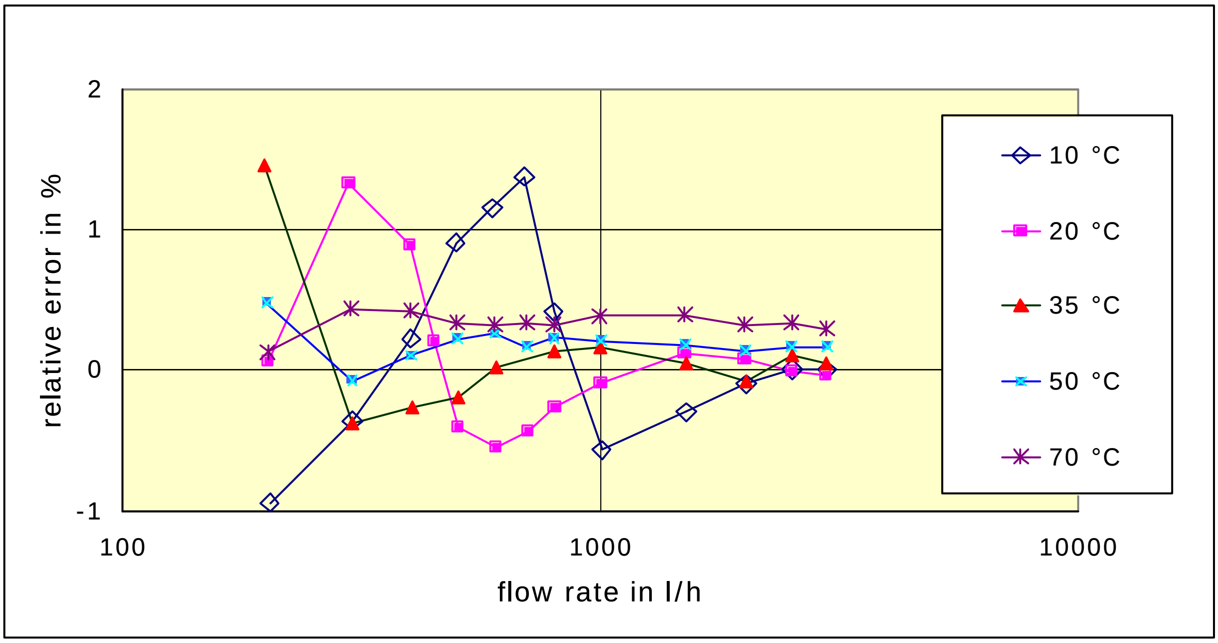


**Figure 3:** Relative error curves of IFS 5000 electromagnetic flow sensors with nominal width DN 15 (heat conveying liquid: propylene glycol-water-mixture)

Ultrasonic flow sensors qualified for the heat conveying liquid water show large errors with the medium propylene glycol-water-mixture (figure 4).

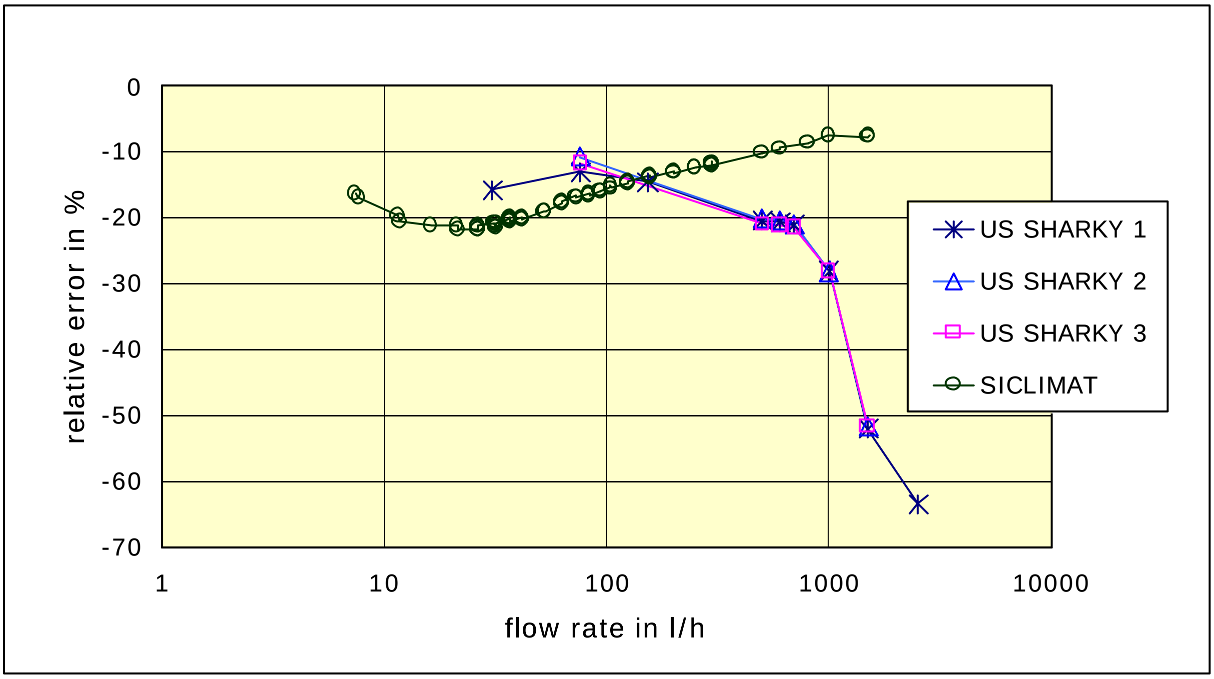


**Figure 4:** Relative error curves of two types of ultrasonic flow sensors (heat conveying liquid: propylene glycol-water-mixture)

Only the electronic vane-wheel flow meters are qualified for their application in small thermal solar systems. Therefore the results of these flow meters will be discussed in a more detailed way.

Each relative error curve of the CF concerning a particular vane-wheel flow meter at a fixed temperature (and at a fixed glycol concentration of the mixture of the heat conveying liquid) shows typically with decreasing flow rate - coming from the highest flow rate - a minimum followed by a maximum, which is caused by the turbulent-laminar transition of the flow inside the sensor. At the lowest flow rates the error curve descends from the maximum to the starting error curve of the vane-wheel flow meter. Varying the temperature or the propylene glycol concentration of the mixture the error curves of the CF will be shifted along the axis of the flow rate (figure 5).

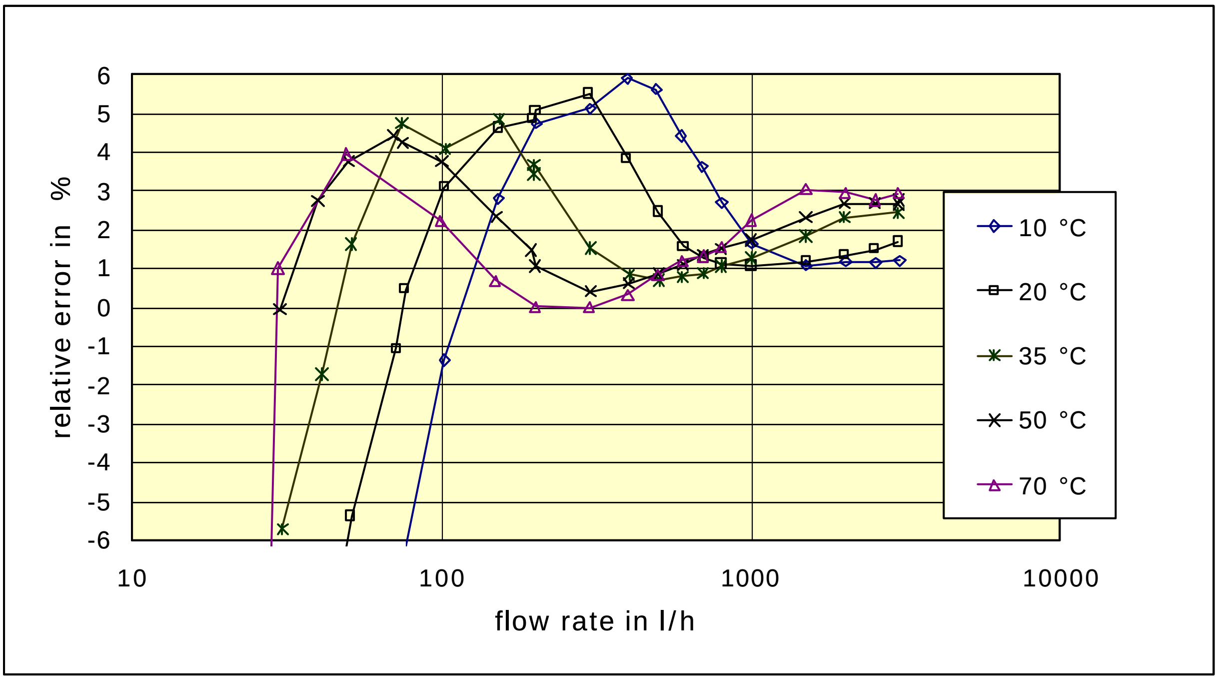


**Figure 5:** Averaged relative error curves of three vane-wheel flow meters of the type 444 with a nominal flow rate of 1.5 m³/h (heat conveying liquid: propylene glycol-water-mixture)

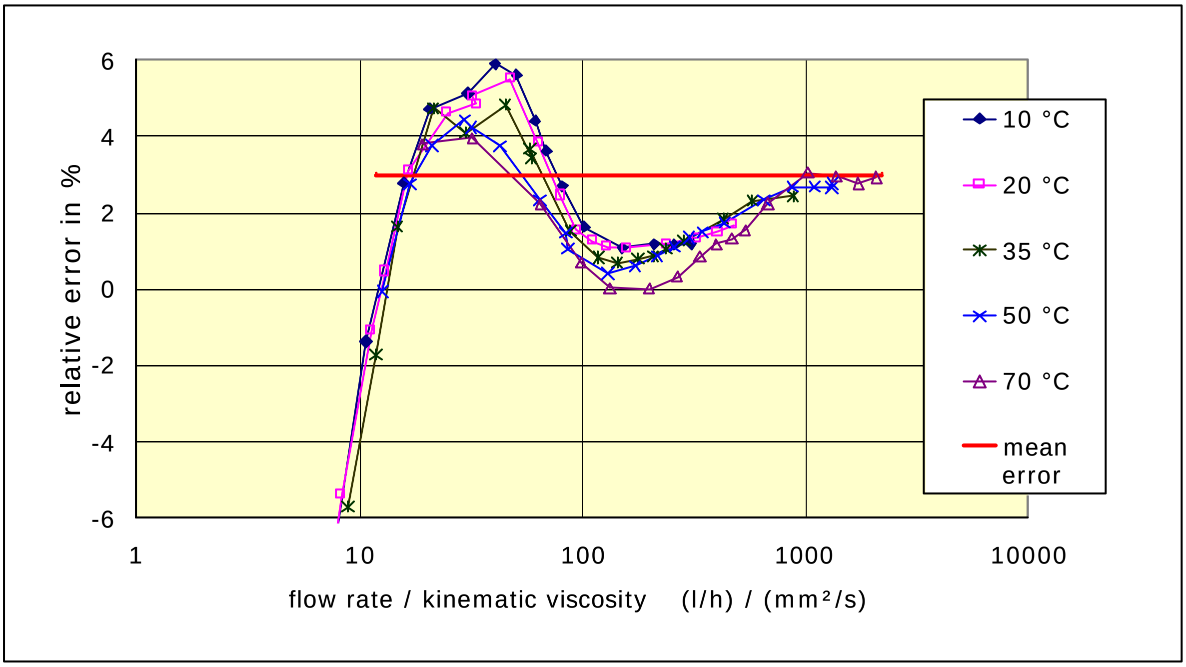


**Figure 6:** Averaged relative error curves of three vane-wheel flow meters of the type 444 with a nominal flow rate of 1.5 m³/h (heat conveying liquid: propylene glycol-water-mixture)

All error curves coincide nearly completely (figure 6), if they were not plotted as a function of the flow rate but plotted as a function of the ratio ”flow rate over kinematic viscosity”, which is proportional to the Reynolds number. The proportional factor is $\pi \bullet D/4$ and D a length characterising the geometric conditions of the flow. To calculate the Reynolds number corresponding to the given flow rate is very difficult, because D is **not** the nominal width of the flow sensor. Therefore this value is usually not known.
For each type the allowed lowest flow rate is given by the starting error curve at the flow rate where the relative error is equal to the relative error of the minimum of the error curve. In table 1, last column, it can be seen the calculated lowest flow rates of the several flow meters at a temperature of 20 °C and a glycol concentration of 50 vol.-% TYFOCOR L of the heat conveying liquid.
The largest flow rate (which is allowed for 10 % of the period of operation) is twice of the nominal flow rate (table 1, column 8). For the flow meter type 444 the range between the lowest flow rate and the largest flow rate is characterised in figure 6 with a solid red line.

**Table 1:**

| type-name | number of meters | Calibration Factor (CF) pulses/l test | normal | greatest relative variation of the CF % | relative mean error of the CF % | relative spread of the CF % | nominal flow rate m³/h | lowest flow rate 50 vol.-% 20 °C l/h |
|---|---|---|---|---|---|---|---|---|
| ES-Sensor | 3 | 125 | 1 | 4 | 1.0 | ± 0.7 | 0.6 | 45 |
| Integral MK | 1 | 125 | 1 | 4 | 2.0 | - | 1.0 | 40 |
| EWZ * | 3 | 267 | 1 | 3 | 1.5 | ± 0.3 | 0.6 | 47 |
| EAW | 3 | 51.46 | 0.1 | 3 | 0.0 | ± 0.4 | 1.0 | 180 |
| 444; 1.5 | 3 | 30.34 | 1 | 4 | 3.0 | ± 0.6 | 3.0 | 70 |
| PolluCom M * | 3 | 25.6 | 25.6 | 6 | 1.5 | ± 0.7 | 1.5 | 95 |
| AMTRON N * | 5 | 29.526 | 1 | 4 | 2.0 | ± 0.9 | 1.5 | 130 |
| 444; 0.6 | 1 | 83.4 | 1 | 6 | 3.0 | - | 0.6 | 70 |

Characteristic data of several electronic vane-wheel flow meters (single-jet and multi-jet). Multi-jet flow meters are signed with *.

Fortunately the relative error curve of the worst type of the investigated electronic vane-wheel flow meters showed a greatest relative variation of CF of 6 % (table 1, column 5) between the value of the maximum at the laminar-turbulent transition and the value of the minimum at higher flow rates whereas the meters tested by Adunka et al. [1] showed differences up to about 12 % (single-jet vane-wheel flow meter) or up to 9 % (multi-jet vane-wheel flow meter). The best devices had a greatest relative variation of CF of 3 % (table 1, column 5). The mean relative errors of the CF of the sensors concerning their flow rate measurement ranges vary depending on the type from 0 % up to 3 % (table 1, column 6).
The relative spread of the CF of a given type of an electronic vane-wheel flow meter is given by the averaged deviations of the errors of the CF of all devices of one type from their mean error in their measurement range.
The repeatability of results of measurements with respect to the CF were determined by the experimental standard deviations under repeatability conditions concerning temperature, flow rates and glycol concentration of the mixture. These deviations varied for the different types under different conditions relatively between 0.1 % and 0.6 %.

Figure 7 shows the starting errors curves of several types of single-jet and multi-jet vane-wheel flow meters. in dependency on the ratio ”flow rate over kinematic viscosity”.

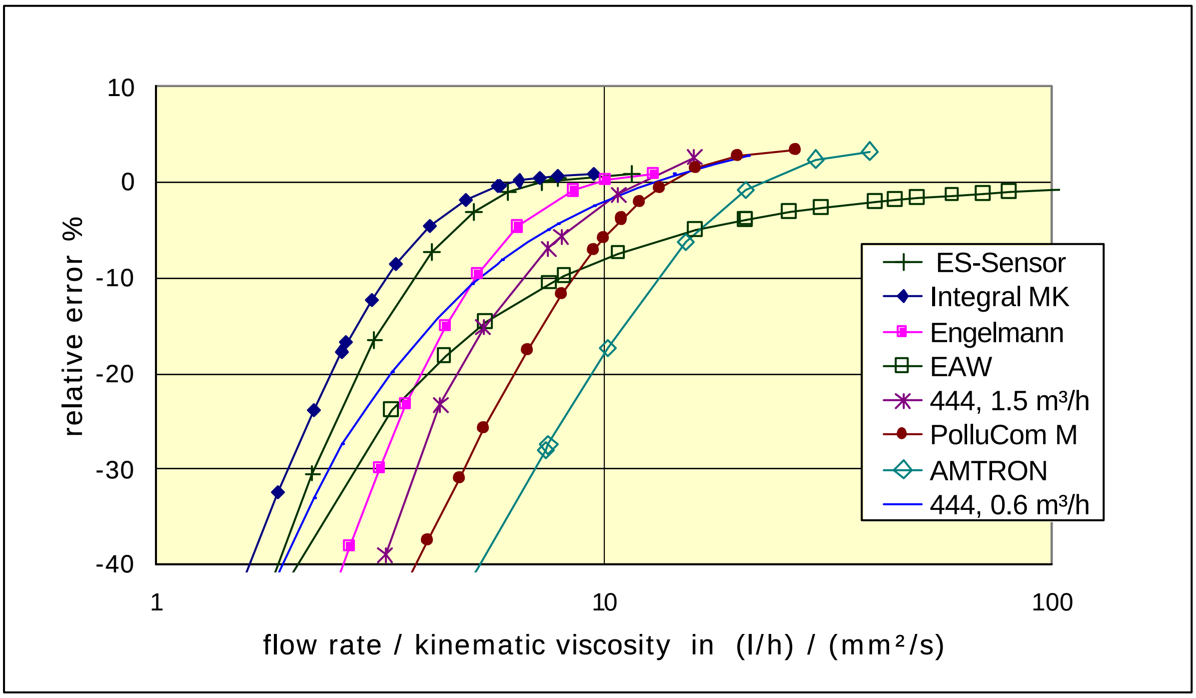


**Figure 7:** Starting error curves of electronic vane-wheel flow meters (heat conveying liquid: propylene glycol-water-mixture)

With this figure it is possible to determine the lowest allowed flow rate for each tested flow meter at a given mixture and a given lowest temperature.
The results of all tested flow meters has been described in detail in PTB Bericht PTB-ThEx-14 [2]

## Conclusion

Among the investigated flow sensors - turbine meters, electromagnetic flow sensors, ultrasonic flow sensors and vane-wheel flow meters (single-jet and multi-jet) - only the vane-wheel flow meters are qualified for operation in (small) thermal solar systems with a propylene glycol-water-mixture as heat conveying liquid. The error curves of the CF of the meters are similar for different mixtures and different temperatures, if they were plotted in dependency on the ratio "flow rate over kinematic viscosity".

## References

[1] Adunka, F. and Kolaczia, W., Zur Fehlerkurve der Flügelradzähler bei Flüssigkeiten mit hoher Viskosität, Fernwärme international – FWI, pp. 329-334, issue 6; vol. 13, 1984
[2] March, J.-F., Der Einfluss von Glykol-Wasser-Gemischen auf die Messrichtigkeit von Wärme-zählern für thermische Solaranlagen, PTB Bericht PTB-TthEx-14 , 2000