GEOTHERMAL PIPE NETWORK SIMULATION SENSITIVITY TO PIPE SURFACE ROUGHNESS

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ABSTRACT - Numerical simulation of a pipe network system is used to demonstrate the sensitivity of network pipe flows and pressures to changes in surface roughness. The range of values used is from 0.0000457m to 0.0005m. The results demonstrate that the effects on the performance of the network due to the surface roughness changes for the range investigated are small.

1. INTRODUCTION

This paper presents the results of the study on the pipe network simulation sensitivity to surface roughness. The reinjection pipe network in Ohaaki Power Station is used for the investigation of the sensitivity. A recently updated computer model was successfully used for all the simulations in this study.

In the process of pressure drop calculation of a pipe network, the pipe surface roughness is used as one of the input data, which will affect the frictional pressure drop and flows within each pipe of the network. However the sensitivity of the output to changes of the pipe surface roughness is unknown and this study identifies the magnitude of these changes. It is also of practical significant to compare the network performance with different pipe surface roughness values in order to predict possible changes in output with time due to surface condition from scaling or corrosion.

A conventional value of surface roughness for commercial steel or wrought iron pipe, ie. ε=0.0000457 m, was used in the simulation for the evaluation of a calculated Fanning friction factor which is dependent upon Reynolds number and relative roughness. It was compared with a simulation using a constant Fanning friction factor. Comparisons were also made for a series of different roughness values ranging from 0.0000457 to 0.0005m which are possible pipe surface conditions. Sensitivity analysis results have shown that the above change of the roughness value has little effect on the performance of the pipe network.

2. ROUGHNESS IN THE MATHEMATICAL MODEL OF A SIMULATION

According to Darcy equation, the frictional pressure drop along a pipeline can be written as

$$\Delta P = \frac{\lambda L}{D}\frac{\rho V^2}{2} \quad \text{(Pa)} \qquad (1)$$

or

$$\Delta P = \frac{4 f L}{D}\frac{\rho V^2}{2} \quad \text{(Pa)} \qquad (2)$$

where ΔP is frictional pressure drop, λ is friction factor as read in the Moody diagram, L is pipe length, ρ is water density, V is water velocity, D is pipe diameter and f is the Fanning friction factor.

As mass flow rate is related to flow velocity V

ie. $$m = \rho V \frac{1}{4}\pi D^2 \quad \text{(kg/s)} \qquad (3)$$

where m is water mass flow rate, equation (2) can then be written as

$$\Delta P = \frac{32 f L}{\pi^2 D^5 \rho} m^2 \quad \text{(Pa)} \qquad (4)$$

Equation (4) shows the relationship between the mass flow rate and frictional pressure drop. For geothermal pipes the Fanning friction factor can be calculated with the von Karman's equation (Schlichting, 1979):

$$\frac{1}{\sqrt{f}} = -4\log\left(\frac{\varepsilon}{3.7 D}\right) \qquad (5)$$

Thus, the pipe surface roughness ε and diameter D are the control elements for evaluation of the Fanning friction factor . In engineering practice, a conventional value of roughness is that for commercial steel or wrought iron pipe, ie. ε=0.0000457 m (Perry et al, 1987). Higher values up to ε=0.0002 m was suggested from some research results (Eliasson et al, 1982). Pipe surface roughness may even have different values for the different pipelines of a network. As for the simulations in this study, a unified pipe surface roughness was assumed for the whole network. Comparisons were made with changes in roughness in the simulations. This approach can also be used to predict the change in a network performance as roughness changes with time.

3. PIPE NETWORK SYSTEM FOR THE SIMULATION

The reinjection pipe network in Ohaaki Power Station was used for the simulation in this study. Fig.1 is the layout of the network system in which **5** separation plants are the sources and 8 reinjection wells are the sinks. At each separation plant a reinjection pump **has** been taken into account with a **fixed** head lift purely to simplify the model. **A** booster pump is located on the down-stream side of the separation plant **SP4,** which gives a fixed head lift of 10 bar. The production curves of mass flow rate versus pressure at each separation plant are given for the simulation. The injectivity, ie. reinjection mass flow versus wellhead pressure, for the reinjection wells are given from well test data. The computer simulation calculates for a stable balanced mass flow rate in each pipeline.

To accomplish a simulation task on a pipe network, a conceptual model of the network is needed. Fig.2 shows the conceptual model of the reinjection pipe network in Ohaaki. **As** illustrated in the model, there are twenty-three unknown mass flow rates to be solved. With the help of the dummy pipe, ie. the dashed lines in the model, the computer code gives a numerical solution for the balanced system (Huang et al, 1992).

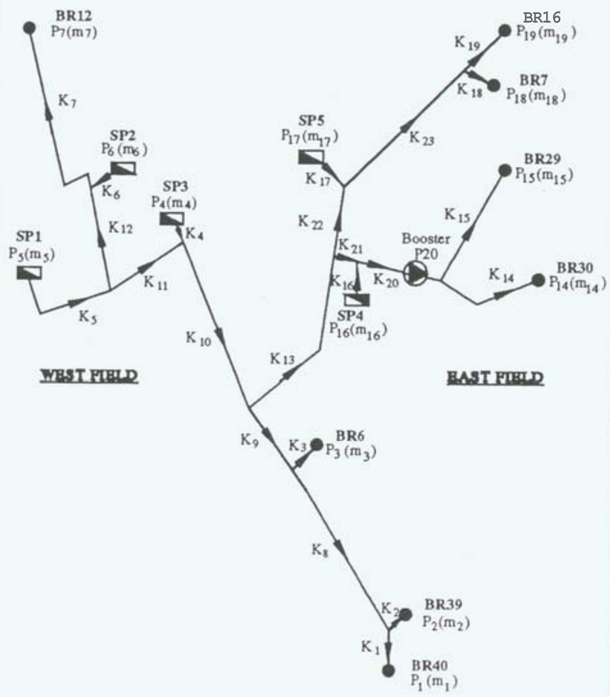


Fig.1 Layout diagram of the reinjection pipe network at Ohaaki Power Station

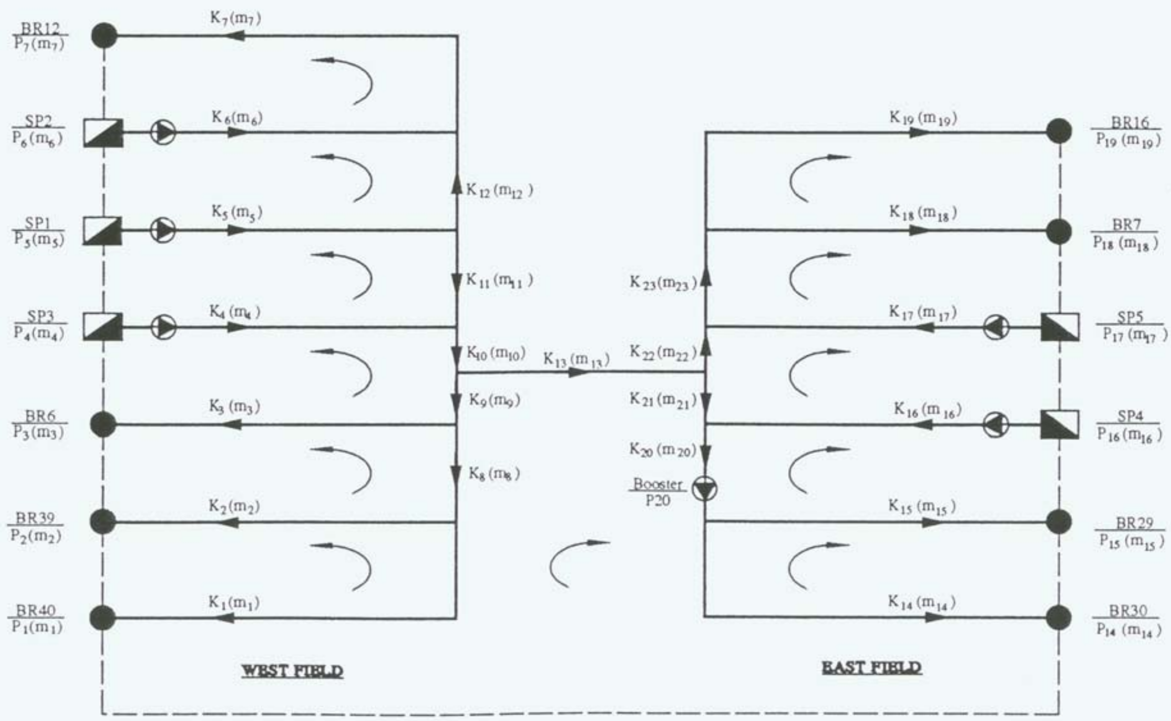


Fig.2 Conceptual model of the reinjection pipe network in Ohaaki

4. NUMERICAL SIMULATION RESULT AND SENSITIVITY ANALYSIS

A series of simulations each with different values of pipe surface roughness was produced in this study. Measurement data of the production and reinjection rate in the system were used for an error analysis of the simulation. The comparisons of results are made as follows.

Simulation with Constant and Calculated Fanning Friction Factors

In Equation (4), the friction pressure loss calculation, Fanning friction factor f should be defined before the simulation.

First, a constant value of f=0.0033 was used for all pipes in the system. This value is believed to be a typical one for geothermal pipe engineering. The numerical solution of the mass flow rates among the 23 pipelines are shown to be close to the measurement data. An error analysis for the simulation result compared to that measured shows that the relative error of the numerical solution for mass flow rates are between 4.2% and -8.1%.

Secondly, the calculated Fanning friction factors were used in the simulation. A constant pipe surface roughness, ie. ε=0.0000457 m, was used for all the pipelines in the evaluation of Fanning friction factors. With all the calculated values of f, the numerical solution for the network gives a small change in magnitude. Fig.3(a) shows the comparison between the measurement and the simulation results, again is close to the result for the constant Fanning friction factor. The error analysis on the simulation result in Fig.3(b) shows only about 1% improvement in the relative error against the measurement. All the relative errors are between 4.2% and -7.1% as illustrated in Fig.3 (b).

Thirdly, a comparison between the simulations with the constant and calculated Fanning friction factor is presented. According to the results of the above two simulations it is expected that the difference between the two are small. Fig.4(a) shows the comparison between the two results, in which the constant and calculated Fanning friction factors were used individually. From the error analysis for the two results in Fig.4(b), it is found that the maximum relative error between the two numerical solution of mass flow rate is less than ±1.0%.

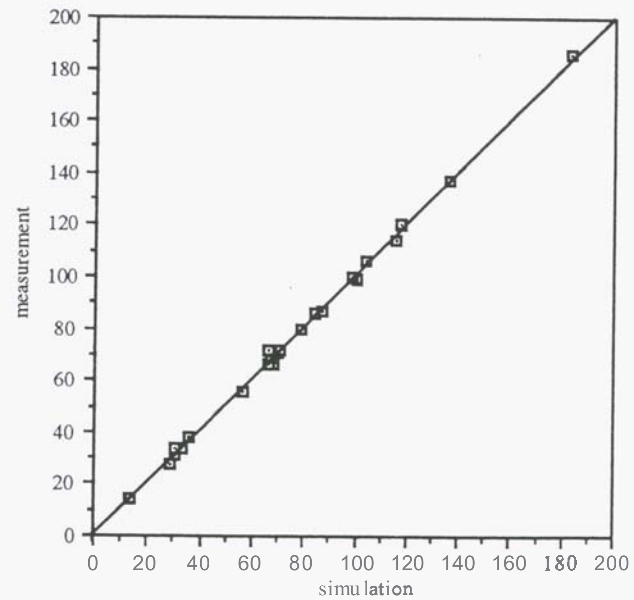


Fig.3 (a) Comparison between the measurement and the simulation with the calculated Fanning friction factor

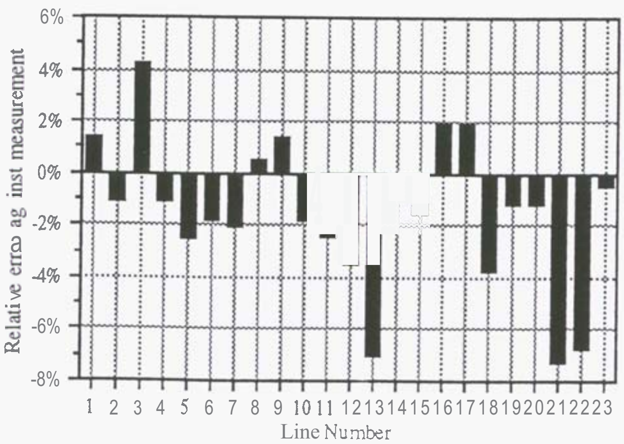


Fig.3 (b) Error analysis on simulation with tlie calculated Fanning friction factor

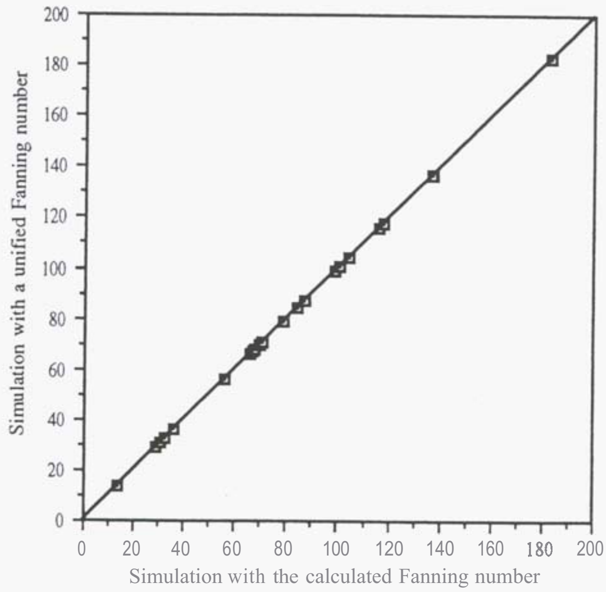


Fig.4(a) Comparison between constant and calculated Fanning friction factors

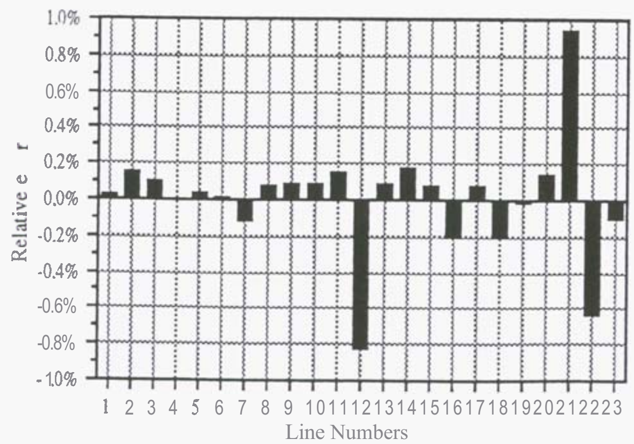


Fig.4 (b) Error analysis for constant and calculated Fanning friction factors

Simulation With Different Pipe Surface Roughness

It is suggested that different pipe surface roughness values would influence the performance of an pipe network. Comparisons from the simulation for pipes with with different surface roughness are presented. Fig.5 shows the error analysis on the simulation results using pipe roughness value of 0.0001, 0.0002, 0.0003, 0.0004 and 0.0005 m respectively. These results are compared with the one with roughness= 0.0000457. The maximum relative error or rather, the maximum relative decrease in **mass** flow rate among the **23** pipelines when the roughness is increased to 0.0002m is 3.6%, which becomes 6.8% for a roughness of 0.0005m. Fig.6 (a), (b) and (c) show comparisons of the mass flow rate sensitivity to pipe surface roughness among the pipelines. **As** expected, the mass flows of all the pipelines decline with the increase of the roughness values.

5. DISCUSSION

The simulations carried out on the reinjection pipe network for Ohaaki Power Station have presented a sensitivity study on the performance of the network to pipe roughness. The results for the different values of roughness demonstrate that in the range of 0.0000457 - 0.0005 m, mass flows and pressures in the network pipes do not change significantly.

The comparison between the results for constant and calculated Fanning friction factors has also confirmed that the simulation is not roughness sensitive. So that a small variation of the pipe surface roughness with time should not cause any significant effect on the network performance. It also proves that the unified Fanning friction factor of 0.0033 is a properly chosen one for the numerical simplicity and engineering accuracy of this simulation.

The maximum relative change of mass flow rate, with an increasing roughness up to 0.0005 m, is -6.8% found in **Fig.5**. The top value of 0.0005 m would **be** a typical roughness for concrete which may also be used for the aged geothermal pipeline with a layer of scale or deposition. The maximum -6.8% change in mass flow give a quantity of the possible drop of the mass flow rate which is important data for network performance prediction. In **Fig.6(a),** (b) and (c) the mass flow rate under different roughness values for some pipelines are plotted. In most of the pipelines, there are declines in **mass** flow rates as the roughness is increased, although the declines are small. It is found that the slope of each curve or the speed of the declines are not the same. It seems that the larger diameter of the pipeline, the more its mass flow rate will decline. In **Fig.7(a),** (b) and (c) the curve are plotted for the pipes with the same diameters respectively, and the above description is confirmed. For the curves with the same pipe diameter, the slopes were found very similar. In Fig.7(a) the top curve has a steeper slope than other curves because of its larger mass flow rate; and in Fig.7(b) the bottom curve has a flatter slope than other curves because of its smaller mass flow rate.

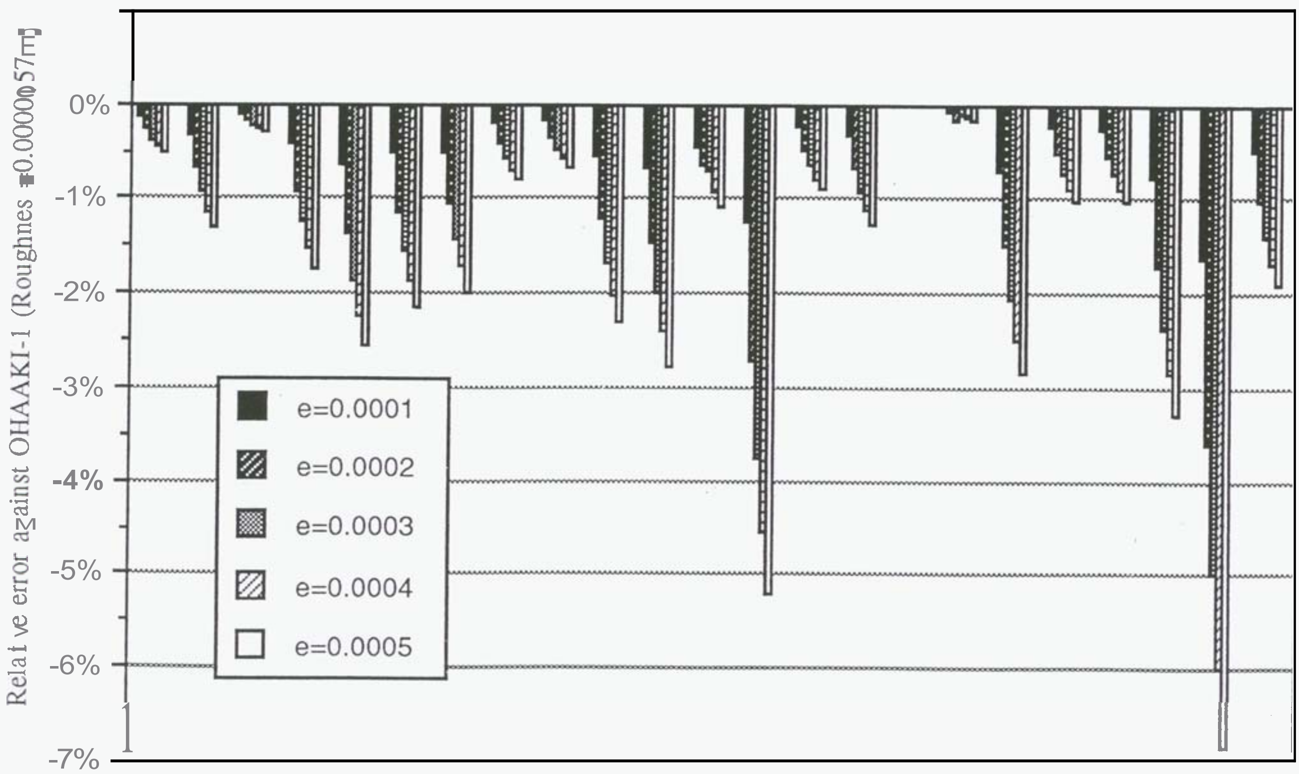


Fig.5 Error analysis on the simulation results for different pipe surface roughness , e in meter

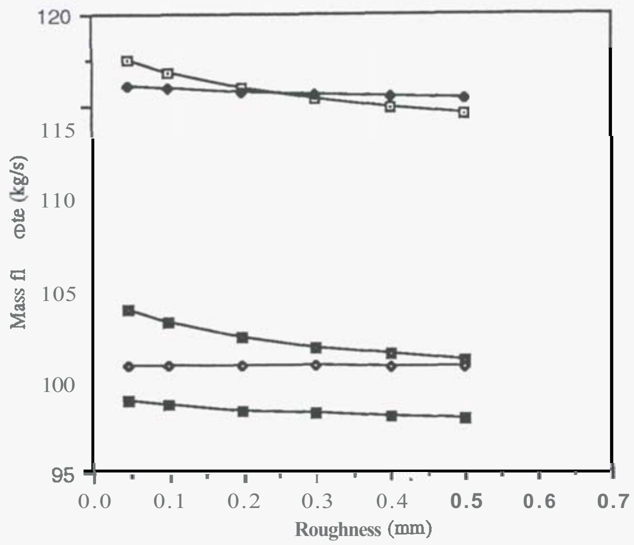
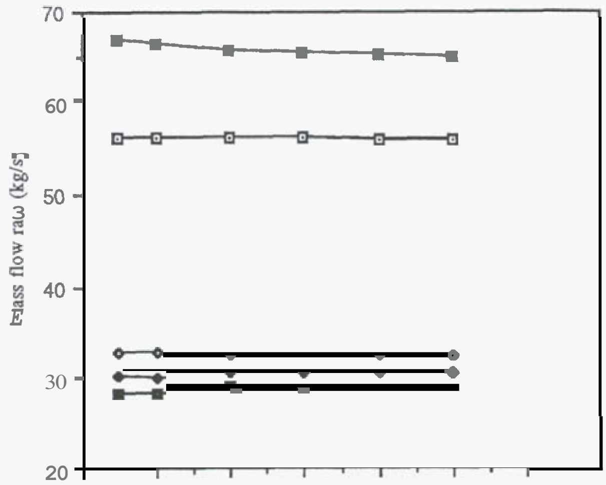


Fig.6(a) Mass flow rate versus pipe surface roughness
(mass flow range 95-120 kg/s)



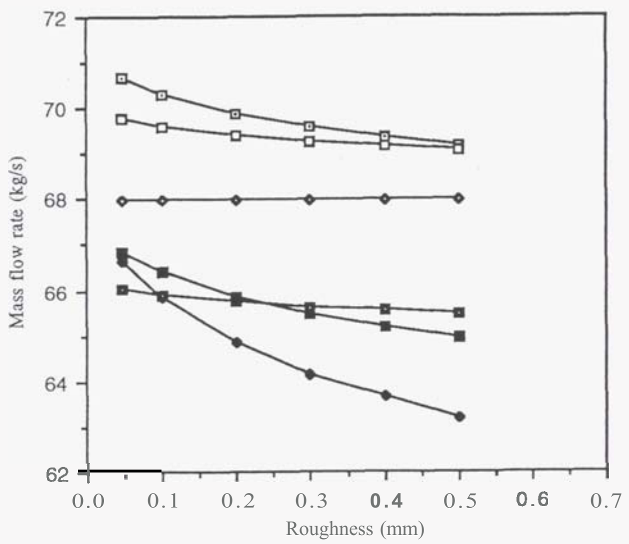
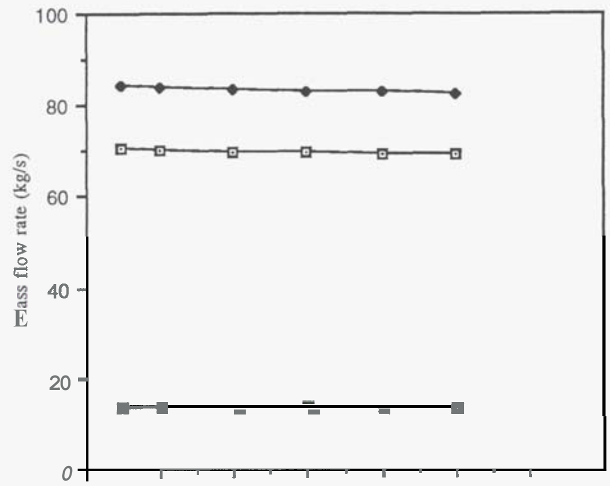


Fig.6(b) Mass flow rate versus pipe surface roughness
(mass flow range 62-72 kg/s)



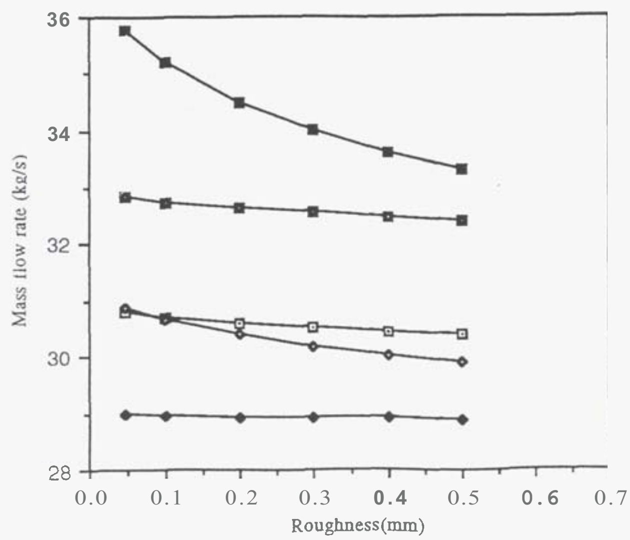


Fig.6(c) Mass flow rate versus pipe surface roughness
(mass flow range 28-36 kg/s)

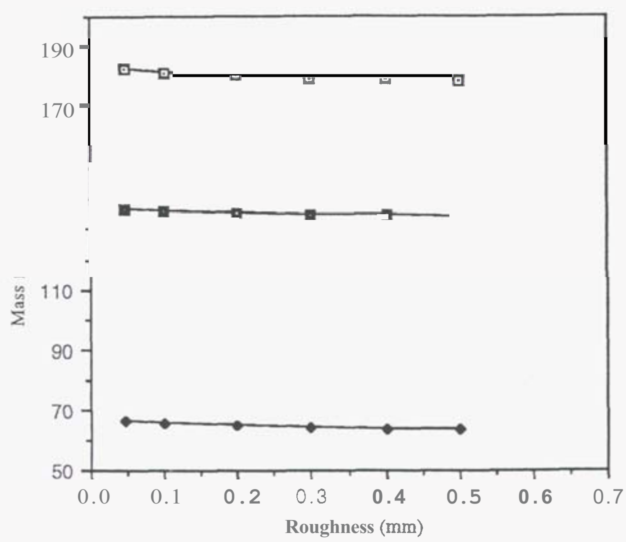


Fig.7(c) Mass flow rate versus pipe surface roughness for pipe diameter of 0.40m

It is also found that: (a) the larger the pipe diameter, the steeper the curve would be, and the mass flow rate would be more sensitive to roughness. (b) the larger the pipe surface roughness is, the less sensitive it is to the mass flow rate. The above description is consistent with the definition in equation (4) and (5) for pressure drop calculation.

Another factor to the sensitivity **of** mass flow is the pipeline length. This is obvious and was also proved by the simulation results.

From the simulation exercises on the pipe network **at** Ohaaki Power Station, no evidence has been found for a divergency caused by the increase of pipe surface roughness up to 0.0005 m. The effect **of** the increase of roughness will not cause a significant unbalance of the network for the given operating condition.

6. CONCLUSIONS

(1) The numerical simulation result of the reinjection pipe network at Ohaaki Power Station is not sensitive to the pipe surface roughness of the range 0.0000457 **-** 0.0005 m.

(2) **A** constant Fanning friction factor of 0.0033 can be used for a simplified yet accurate numerical calculation for the pipelines of a surface roughness of 0.0000457 m. The relative error of the calculated mass flow rate caused by the simplification is less than ±1%.

(3) With the same pipe diameters, the pipeline with the larger mass flow rates will be subject to a larger mass flow rate decline should the pipe surface roughness be increased.

(4) The larger the pipe surface roughness, the less sensitive the mass flow rate is to changes; the longer the pipeline is, the more sensitive would the mass flow rate be to changes in pipe surface roughness.

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