Eighth Australasian Fluid Mechanics Conference, University of Newcastle, N.S.W., 28 November/2 December 1982.

AIR CHAMBER DESIGN CHARTS

H.R. GRAZE AND H.B. HORLACHER

DEPT. OF CIVIL ENGINEERING
UNIVERSITY OF MELBOURNE
PARKVILLE, VIC. 3052 AUSTRALIA

INSTITUT FUR WASSERBAU
UNIVERSITY OF STUTTGART
7000 STUTTGART WEST GERMANY

SUMMARY A preliminary design for an air chamber installation generally bases its initial air chamber dimensions on data provided nearly three decades ago by Evans and Crawford (1954), or on modified charts subsequently developed by Graze and Forrest (1974) or by Ruus (1977). In all these cases, the boundary condition of the behaviour of the entrapped air in the air chamber was described by the empirical polytropic equation having an index of 1.2. Furthermore, these charts only provided extreme pressure head values at discrete points.

The present charts however include the polytropic index as a variable so that different indices may be chosen for maximum and minimum pressure head calculations. The charts also provide extreme pressure head variation along the whole length of the pipeline and the time of occurrence of these extremes.

The charts are extremely simple to use, and their clear layout highlights the important influence of the polytropic index, n.

NOTATION

A	cross-sectional area of pipeline, m^2
a	celerity of waterhammer wave, $m\ s^{-1}$
C	volume of air in air chamber, m^3
g	acceleration due to gravity, $m\ s^{-2}$
h_{atmos}	atmospheric pressure head, m
h_e	static head on pumping system, m
h_f	initial pipeline friction head, m
h_j	Joukowsky's pressure head av_o/g, m
h_{max}	maximum pressure head in pipeline, m
h_{min}	minimum pressure head in pipeline, m
h^*	absolute pressure head, m
L	length of pipeline, m
n	polytropic index of assumed air behaviour
T	period of oscillation, s
t_{hmax}	time for maximum pressure head, s
t_{hmin}	time for minimum pressure head, s
v	velocity in pipeline, $m\ s^{-1}$
ρ^*	pipeline parameter, $av_o/2g(h_o+h_{atmos})$
σ^*	air chamber parameter, $2gC_o(h_o+h_{atmos})/AL\ v_o^2$
Subscript	
o	refers to initial conditions

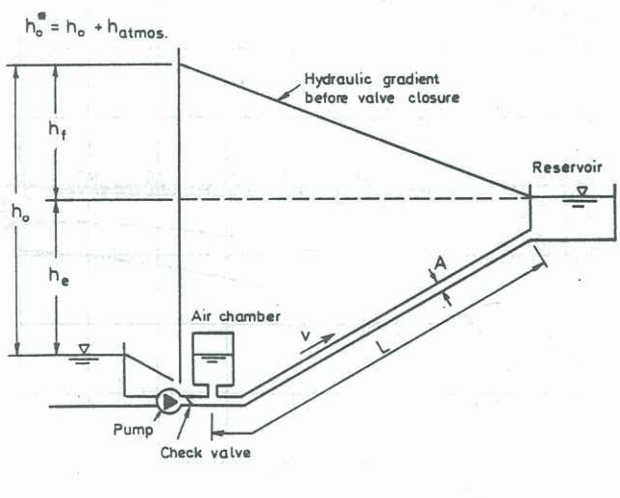

Fig. Schematic Air Chamber Installation

1 INTRODUCTION

Air chambers play an important role in pumping systems, as well as in hydro-electric installations (Graze et al 1974) by controlling the waterhammer pressures resulting from sudden changes in flow conditions.

As a boundary condition in an hydraulic installation, it has been shown that the air chamber behaviour can best be described by the rational RHT theory (Graze 1968, 1972) in which the temperature of the air plays an important role. This concept has been verified with field data (Graze et al 1976, 1977) and air temperature

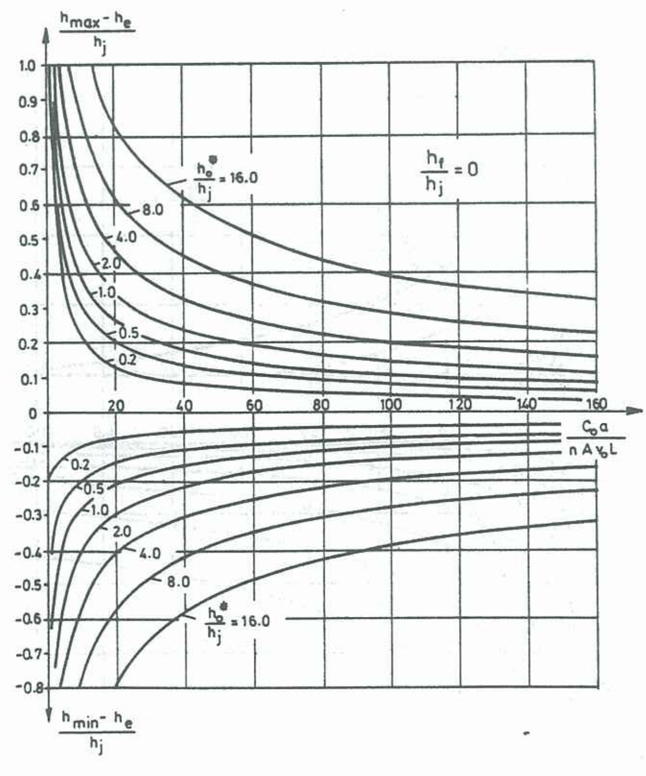

Fig. 2 Extreme Pressure Heads for $h_f/h_j = 0.0$

changes in the order of 95°C, i.e. from -45°C to 50°C, have been recorded in large air chambers following sudden pump stoppage (Schubert et al).

However, the initial sizing of an air chamber is generally carried out with the aid of design charts, wherein the behaviour of the air is assumed to satisfy the empirical polytropic equation, $h^*C^n = \text{const.} = h_o^*C_o^n$. Evans and Crawford, Graze and Forrest, and Ruus have developed such charts wherein the polytropic index, n, is taken to be 1.2. It is encouraging to note that the agreement between these charts is very good.

On the other hand though, the RHT theory and field data clearly show that with the assumption of the polytropic equation, the polytropic index is a variable. It is close to 1.4 (adiabatic) during the initial phase following a sudden change in flow, but subsequent flow phases reveal a large range of possible n values.

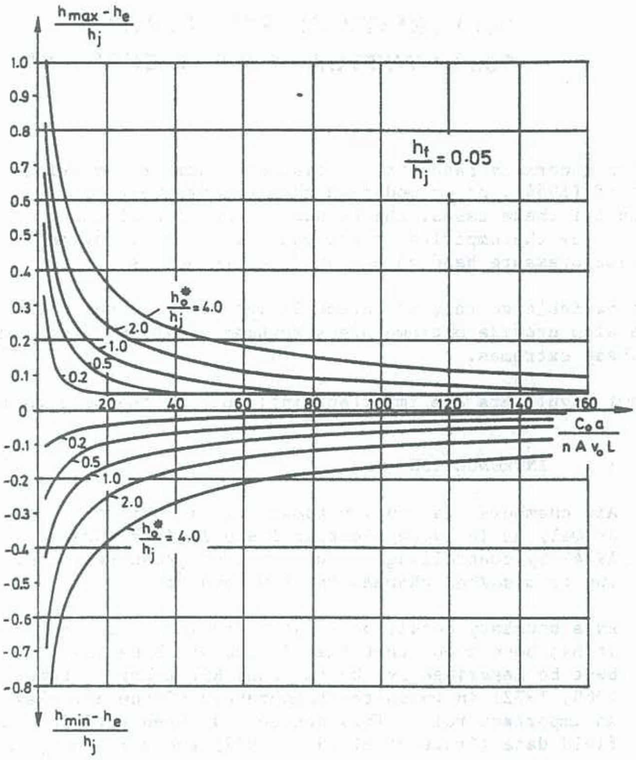

Fig. 3 Extreme Pressure Heads for h_f/h_j = 0.05

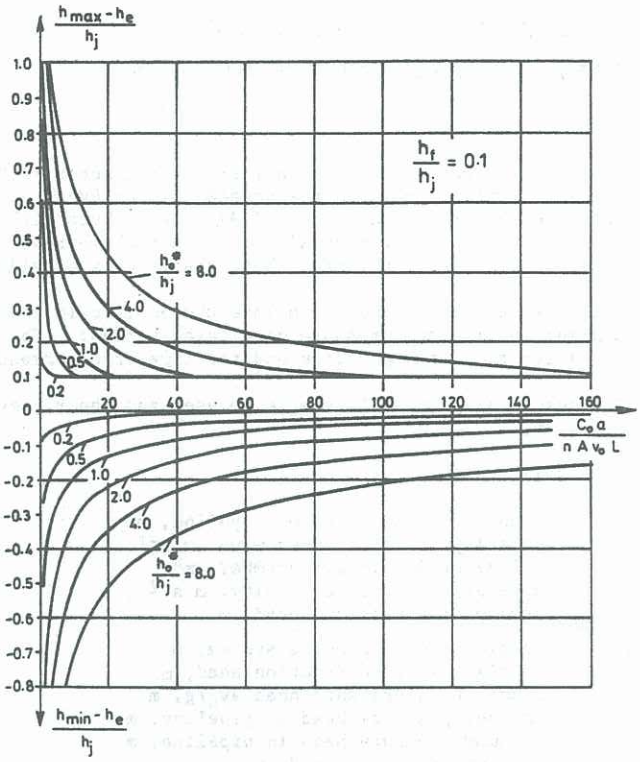

Fig. 4 Extreme Pressure Heads for h_f/h_j = 0.1

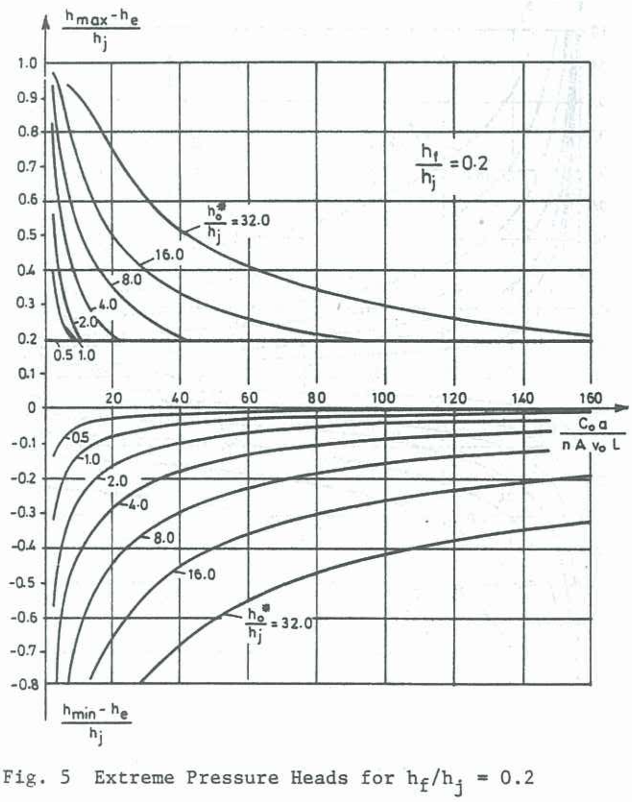

Fig. 5 Extreme Pressure Heads for h_f/h_j = 0.2

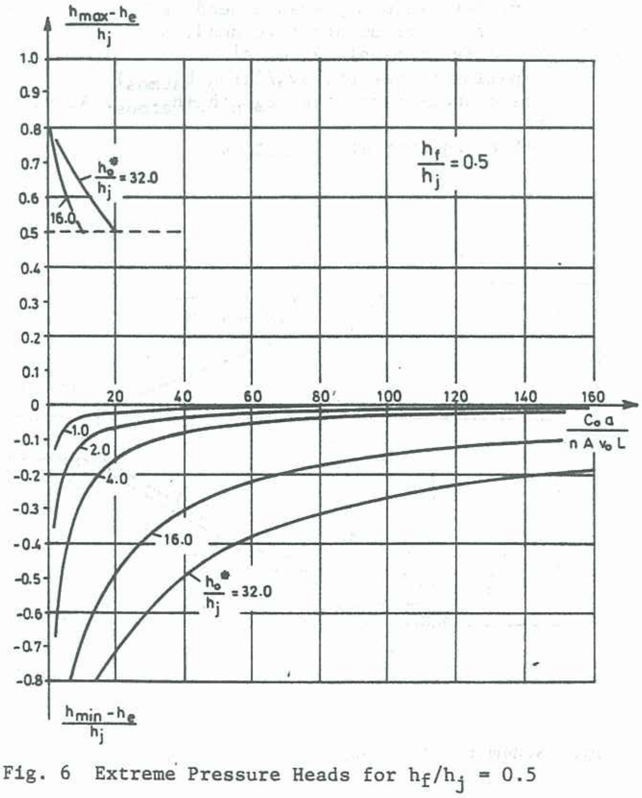

Fig. 6 Extreme Pressure Heads for h_f/h_j = 0.5

Fok has also provided some charts. With these he attempted to improve the previous charts listed above, by depicting pressure data along the whole length of the pipeline instead of only at a few discrete points. However many authors are critical of these charts as evidenced by their discussions of Fok's paper. Thus de Almeida and Hipolito query Fok with "... the author does not explain the discrepancies with other authors." and state "Large orifice loss coefficient may cause some cavitation trouble... making this choice not very popular among some air chamber designers".

Chaudhry makes the following comment "... it has made the use of the charts more complex and may consequently reduce the accuracy of the results." The strongest criticism however comes from Ruus who states, amongst many other comparisons, "When pipe wall friction alone is considered substantial errors occur at the pump end in case of upsurge. This becomes more severe at the mid-point and at the quarter point... the resulting error is 35% on the unsafe side." and "The writer concludes that, except for pump end, Figs. 1 and 2 appear to be grossly in error and cannot be recommended for design in their present form." Following these statements it is surprising that no one has highlighted the inaccuracies in Fok's paper concerning the calculations of the air temperatures in the air chamber.

From the above it is obvious that there is a need to provide air chamber design charts for:

- the allowance of a variable polytropic index, n.
- the determination of the extreme transient pressure along the whole length of the pipeline,
- the losses to be <u>only</u> attributable to pipeline friction, and
- ease of appreciating the influence of the various parameters and of extracting the required data, usually C_o.

This paper intends to satisfy these aims.

2 THEORETICAL CONSIDERATIONS

The method of characteristics was used in the present

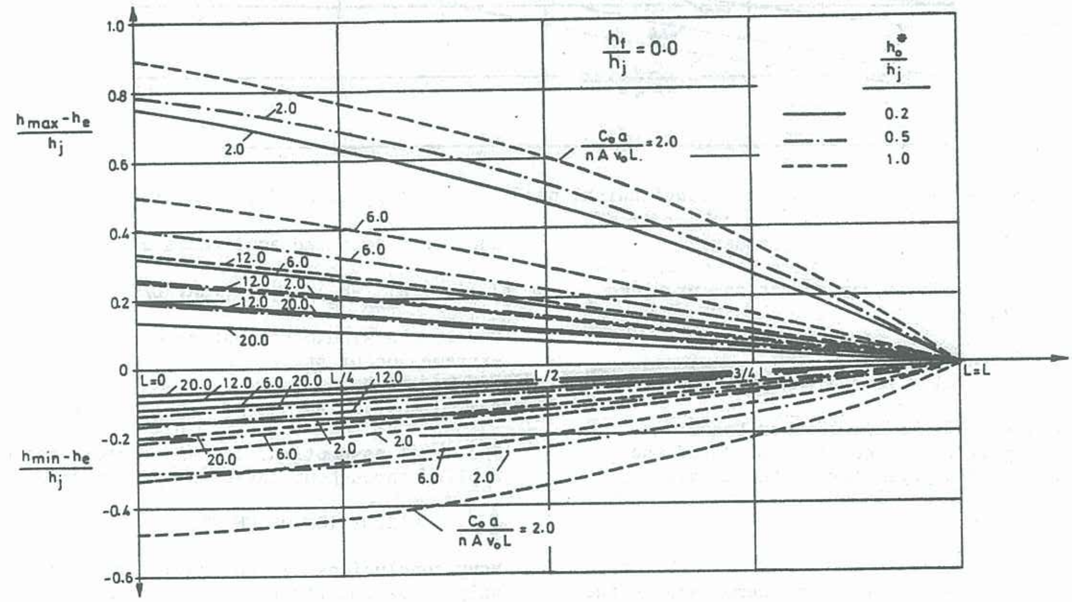

Figure 7 Extreme Pressure Heads along the longitudinal profile of the pipeline for h_f/h_j = 0.0

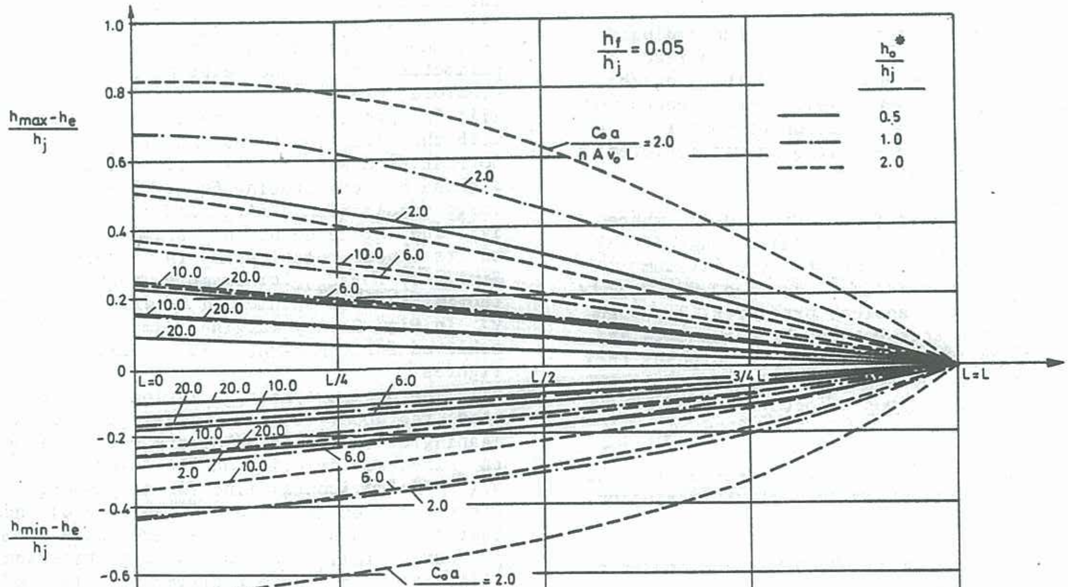

Figure 8 Extreme Pressure Heads along the longitudinal profile of the pipeline for h_f/h_j = 0.05

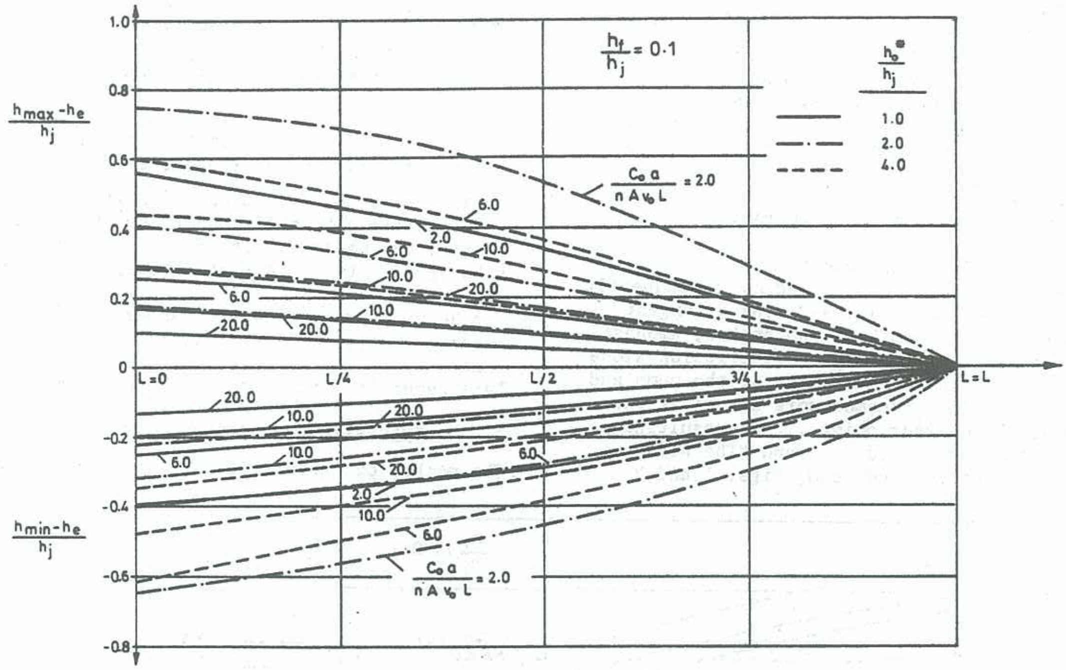

Figure 9 Extreme Pressure Heads along the longitudinal profile of the pipeline for h_f/h_j = 0.1

analysis and non-dimensionalised (Horlacher). Similarly the boundary conditions were non-dimensionalised and the pressure head considerations provided the following parameters:

h_e/h_j - effect of static lift
h_f/h_j - effect of friction loss along pipeline.

The dynamic analysis of the air chamber behaviour, described by the polytropic equation, produced the following dimensionless parameter in the dynamic equation, viz.

$C_o a/nAv_oL$

These three dimensionaless parameters were used in the method of characteristics to provide the extremes of pressure heads and their occurrence as depicted in the attached charts. (Figures 2 - 11).

However for ease of reading the charts, the ordinate for the pressure head graphs was adjusted to read $(h_{max} - h_e)/h_j$ for maximum upsurge, and $(h_{min}-h_e)/h_j$ for maximum downsurge (Figures 2-9). While each chart was developed for a constant friction parameter h_f/h_j, the influence of the static head was depicted on each chart by a range of h_o^*/h_j values.

A similar approach was used for Figures 10-11, where the ordinate became either $t_{hmax}/(L/a)$ or $t_{hmin}/(L/a)$ depicting the dimensionless time when the maximum pressure or the minimum pressure occurred respectively after initiation of the transient pressures.(Although there is a phase difference between h_{max} and C_{min}, and h_{min} and C_{max} (Graze 1971) for practical purposes they can be considered as coincident, and Figures 10-11 may be used to determine the times of occurrence of the extreme volume values.)

In all these charts, the abscissa was reserved for the informative $C_o a/nAv_oL$ parameter or a slight variation of it, as in Figures 7-9.

For the frictionless situation where the amplitudes of pressure oscillations are small, analytical solutions can be derived (Graze 1967).

Thus the period of oscillation, T, is given by

$$T = 2\pi L/a[(C_o a/nAv_oL).(h_j/h_o^*)]^{\frac{1}{2}} \qquad (1)$$

and the associated amplitudes are

$$|(h_{max}-h_e)/h_j| = [(nAv_oL/C_oa).(h_o^*/h_j)]^{\frac{1}{2}} \qquad (2)$$

Due to the sinusoidal nature of the oscillations, the extremes occur at

$$t_{hmin} = T/4 \quad \text{and} \quad t_{hmax} = 3T/4 \qquad (3)$$

The usual assumptions for air chamber design were applied throughout these analyses (Graze, 1974).

3 DISCUSSION OF CHARTS

Many conclusions can be drawn from these charts but only a few important ones are listed below.

i) The charts are self-explanatory, and together with the parameters under 'Notation' are easily used for initial air chamber sizing.
ii) The abscissa $C_o a/nAv_oL$ is directly related to the well known pipeline parameter, ρ^*, and the air chamber parameter, σ^*, by the relation $\rho^*\sigma^*/n$. (Evans and Crawford, Graze and Forrest).
iii) The pressure head charts are in good agreement with the data from Evans and Crawford, Graze and Forrest, and Ruus. This agreement is further highlighted by substituting Eq. 2 into Figure 2 for large values of $C_o a/nAv_oL$ and of h_o^*/h_j.
iv) The influence of 'n' is immediately obvious due to its linear relationship in the abscissa parameter. Similarly for C_o. For example, the effect of doubling the initial air volume can readily be appreciated.
v) In Fig. 2 only marginal damping of the surges is achieved for $C_o a/nAv_oL > 80$. Similarly for the other figures.
vi) The pressure head variations have been plotted about the upper reservoir level, h_e, for a more meaningful appreciation of the surges, especially for the effect of friction on the downsurge.
vii) The horizontal line for the upsurge situation where friction is present (Figures 3-6) indicates that there is no excess pressure above the steady state pressure. This is often a design criterion.
viii) The charts permit different values of n to be used for various phases of the dynamic behaviour. For example, n=1.4 for downsurge and n=1.3 for upsurge as often experienced in practice (Graze et al, 1976, 1977).
ix) Eq. 2 indicates that the pressure heads vary as the square root of n, while the factor $C_o a/nAv_oL$ reveals that the volume varies linearly with n - the

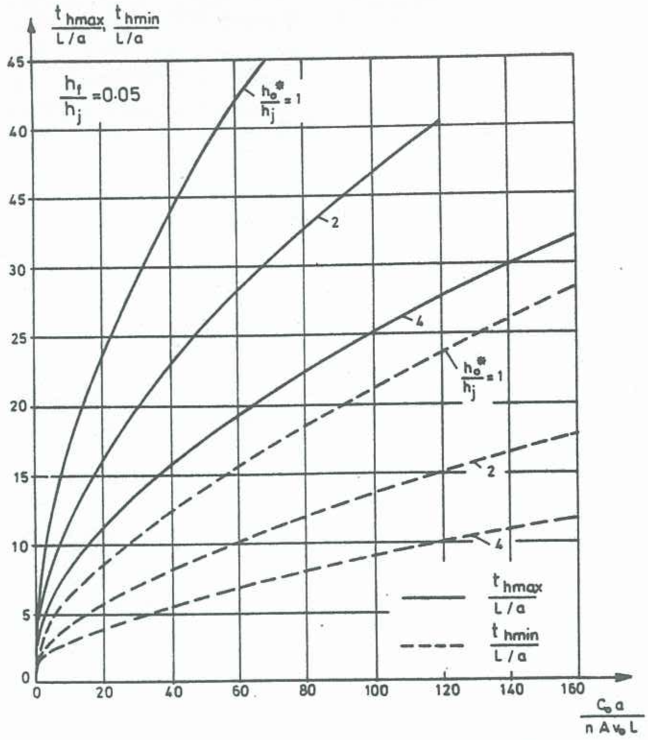

Figure 10 Occurrence of Extreme Heads for h_f/h_j = 0.05

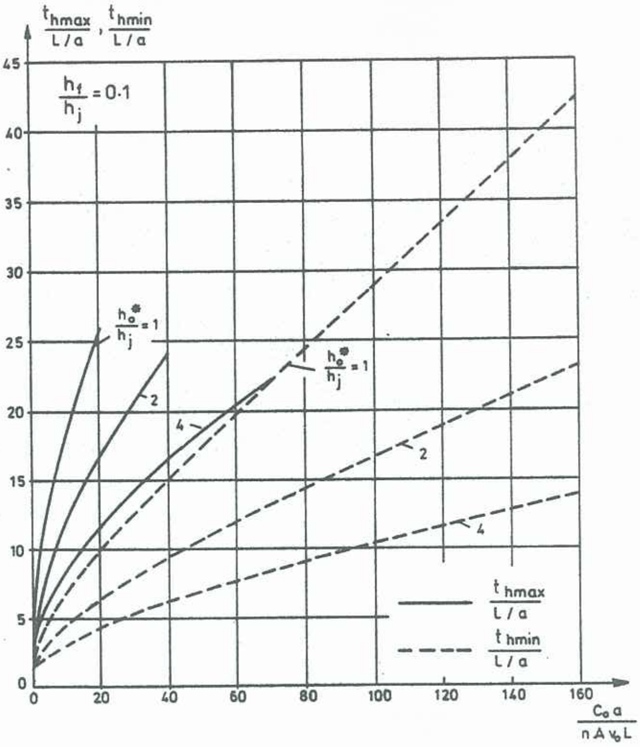

Figure 11 Occurrence of Extreme Heads for h_f/h_j = 0.1

latter indicating a far more sensitive situation.

x) Figures 7-9 highlight the variation of pressure head along the pipeline for the three friction cases h_f/h_j = 0.0, 0.05 and 0.10. These charts are especially useful for critical high points in the longitudinal profile of the pipeline.

xi) The time of occurrence of the extreme pressures for h_f/h_j = 0.05 and 0.1 can be obtained from Figures 10 and 11. For the frictionless situation, Eq. 3 is applicable.

xii) Due to lack of space, only charts with pipeline friction have been included in this paper. However for long pipelines this is generally the case. The data allowing for orifice losses including different valve throttling (Giesecke and Horlacher) will be published at a later date. In the meantime, the influence of an orifice can be gauged from previous charts where n = 1.2 (Graze et al, 1974).

4 CONCLUSION

This paper has presented new air chamber design charts whose virtues lie therein that

- a very useful new abscissa parameter has been introduced, viz. C_oa/nAv_oL,
- the new abscissa parameter includes the polytropic index as a variable permitting a quick sensitivity check on the choice of n,
- the pressure head variation along the pipeline is plotted, and
- the charts are extremely simple to use.

5 REFERENCES

CHAUDHRY, M.H. (1979) Discussion of Paper 14024 by FOK (1978), ASCE, HY10, 105, 1322-1324.

DE ALMEIDA, A.B. and HIPOLITO, J. (1979) Discussion of Paper 14024 by FOK (1978), ASCE, HY10, 105,1324-1325.

EVANS, W.E. and CRAWFORD, C.C. (1954) Design Charts for Air Chambers on Pump Lines. Trans. ASCE,119,1025-1036.

FOK, A.T.K. (1978) Design Charts for Air Chamber on Pump Pipelines. J. Hyd., ASCE, HY9, 104, 1289-1303.

GIESECKE, J. and HORLACHER, H.B. (1981) Throttling Characteristics and Evolution of Water Hammer Pressure for Various Types of Valves. Wasserwirtschaft, 71, 80-85.

GRAZE, H.R. (1967) A Rational Approach to the Thermo-dynamics Behaviour of Air Chambers, Thesis (Ph.D.), University of Melbourne.

GRAZE, H.R. (1968) A Rational Thermodynamic Equation for Air Chamber Design. 3rd Aust.Conf.on Hyd. and Fl. Mech., Sydney, 57-61.

GRAZE, H.R. (1971) New Air Chamber Characteristics, 4th Aust. Conf. on Hyd. and Fl. Mech., Melbourne, 259-265.

GRAZE, H.R. (1972) The Importance of Temperature in Air Chamber Operations. 1st Int. Conf. on Pressure Surges, Canterbury, F2.13-F2.21.

GRAZE, H.R. and FORREST, J.A. (1974) New Design Charts for Air Chambers. 5th Aust. Conf. on Hyd. and Fl. Mech., Canberbury, 34-41.

GRAZE, H.R., SCHUBERT, J. and FORREST, J.A. (1976) Analysis of Field Measurements of Air Chamber Installation. 2nd Int. Conf. on Pressure Surges, London, K2.19-K2.36.

GRAZE, H.R., SCHUBERT, J. and FORREST, J.A. (1977) Field Data Analysis of a Large Air Chamber Installation, 6th Aust. Hyd. and Fl. Mech. Conf., Adelaide, 556-560.

HORLACHER, H.B. (1981) Waterhammer Charts for Single Pipelines. 3R International, 20, 128-133.

RUUS, E. (1977) Charts for Water Hammer in Pipelines with Air Chambers. Can. J. of Civ. Eng., 4, 293-313.

RUUS, E. (1980) Discussion of Paper 14024 by FOK (1978), ASCE, HY9, 106, 1525-1526.

SCHUBERT, J., GRAZE, H.R. and FORREST, J.A. (1979) Versuche an Windkesseln in Wasserversorgungsanlagen gwf-wasser/abwasser, H.9, 120, 427-433.