PEAK OPERATION OF HEATING POWER STATIONS. PROBLEMS ARISING ON THE CONSUMERS' SIDE, II

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Preface

With the fast technical development and changes in the structure of energy carriers, new modern concepts have emerged with respect to the building and operating of heat supplying power stations and the district supply of heat. These new concepts, in turn, suggested the idea to use heating power stations for the generation of peak energy. We speak about this problem from the consumers' aspects, viz. with space heating tap water supply and the heat lost in the pipe system.

The first part dealt with the reasons which justify peak operation, its methods, potentialities, its economic advantages, and measurements performed.

The second part gives an assessment of the features of peak operation from the consumers' side, pointing to the dimensioning, calculation, and modelling methods to be used with this novel type of operation.

6. Verification of the experience

To verify the correctness of the measurement findings by calculation, we shall follow the same sequence.

a) *The pattern of temperature inside the flats*

Due to the fluctuations of the forward going heating water temperature, the radiators' heat dissipation, too, shows fluctuations. Varying heating output causes the variation of the inside temperature of the rooms. The variations in room temperature are, however, not proportional to the changes in output since the better part of the heat introduced into the rooms with increased

* The evolution of the electric model and the electric measurements were performed at the Research Institute of the Electric Industry.

Mr. I. Erdősi, lecturer and Mr. A. Zöld, lecturer, Department I of Heating, Ventilating, Air Conditioning of the Technical University of Budapest contributed to this work. (Chapter 6, pp. 173—179.)

output is turned to warming up the mass of the limiting structures, and not to warm up the air, and the inside surfaces of the walls. The quantity of heat picked up by the limiting structures depends on the heat absorption coefficients of their individual layers, the sequence of the layers, and the changes of output with time. The "heavier" the building structure is, the greater is the heat quantity that it absorbs, and the smaller are the variations in room temperature.

This phenomenon takes place in the same form also in reverse: with a drop in heating output, the drop in the inside temperature will not be proportional. The warmed-up mass of the limiting structures stores a considerable amount of heat and with a drop in heating output, under the effect of the temperature gradient between the air in the space and the limiting structures, they cool down and dissipate their stored heat into the room. The amount of the so released heat depends on the same factors (heat absorption of the layers, the sequence of the layers, the time pattern). In general the "heavier" the limiting structure is, the greater is its heat accumulating capacity and the more heat is sent back into the room on a drop in heating output, and the slighter are the variations in the temperature of the space.

If the variations in output are cyclic in character then, naturally, the amount of heat absorbed by the limiting structures during a full cycle is equal to that returned by them to the room.

Since we have no space to publish the calculation process and its derivations [10, 11, 12], we shall restrict ourselves to describe the end result of the calculation. The examinations carried out in buildings of light-weight, medium-weight and conventional structures, in premises on the top and intermediate floors, in suits and in corner rooms, under extreme conditions of peak operation to establish the fluctuations of the inside room temperature in extreme (most unfavourable) cases — for instance metal-framed light-weight structured buildings, a corner room on the top floor — or two three-hour peak operations with 40°C amplitude — have shown that the fluctuations of the temperature inside the rooms amounted to maximum 3°C.

b) *Hot tap water supply*

From the measurements of the time pattern of hot water consumption prior to peak operation it was established that while on weekdays there are two consumption peaks, one between 6 and 8 in the morning, and one between 18 and 20 in the afternoon, on Saturdays hot water consumption is relatively uniform. Sundays showed one peak in the late morning hours (Fig. 4) during which some 30 to 35 per cent of the total is consumed.

Peak operation twice a day, in line with the maximum electric demand, by and large coincides with the hot tap water consumption peaks. In this

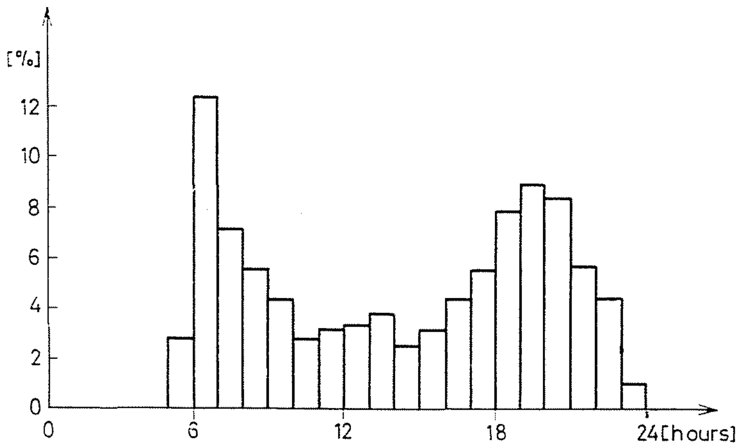

Fig. 4a. Pattern of the hot tap water consumption of a 32-flat block — on weekdays

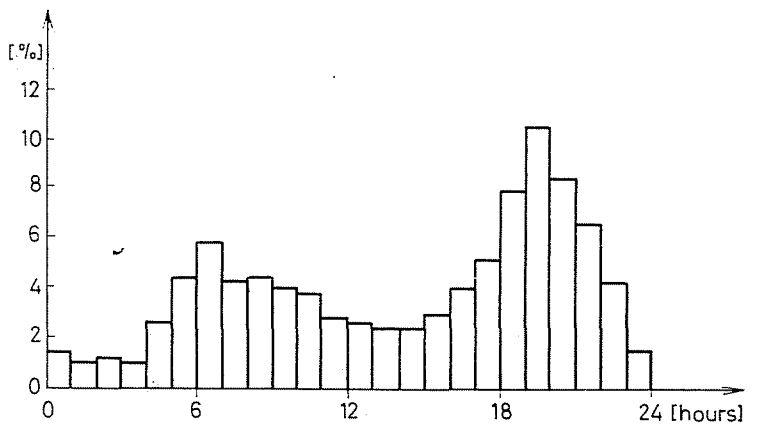

Fig. 4b. Pattern of the hot tap water consumption of a 100-flat block — on weekdays

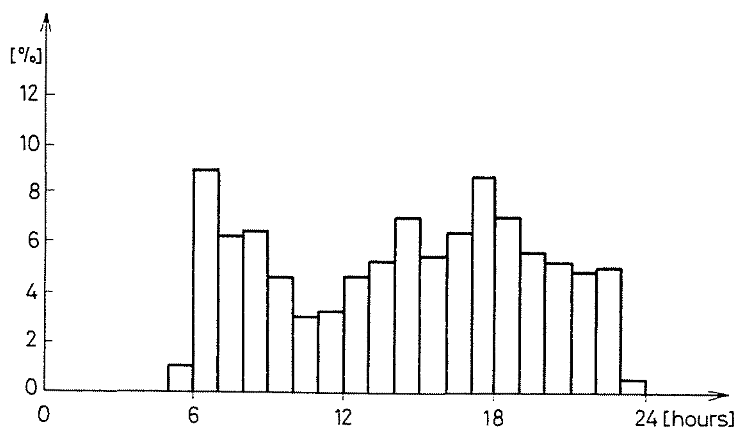

Fig. 4c. Pattern of the hot tap water consumption of a 32-flat block — on Saturdays

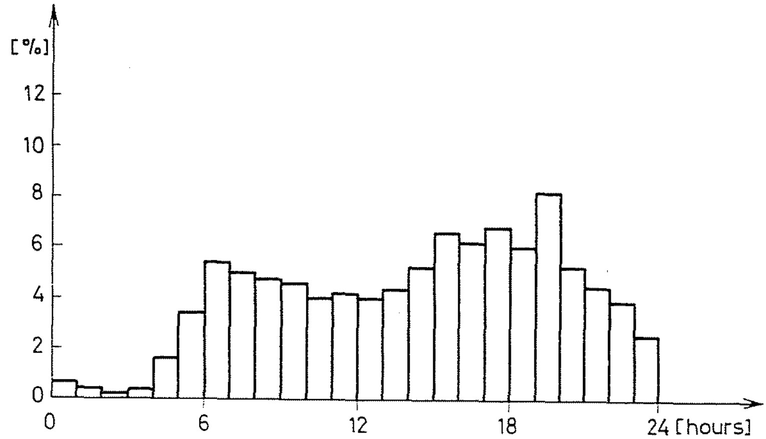

Fig. 4d. Pattern of the hot tap water consumption of a 100-flat block — on Saturdays

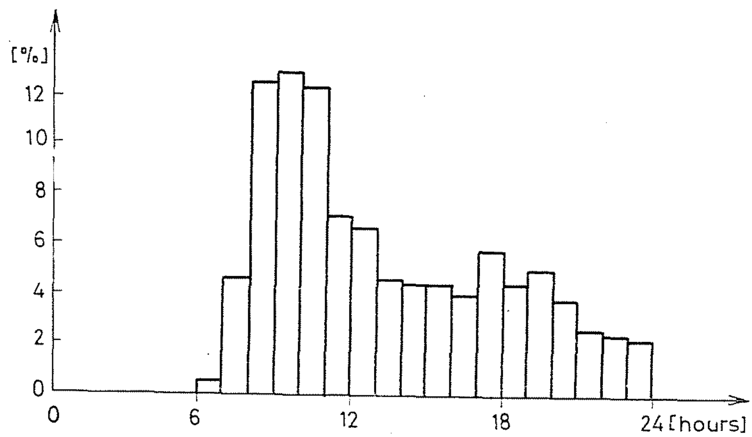

Fig. 4e. Pattern of the hot tap water consumption of a 32-flat block — on Sundays

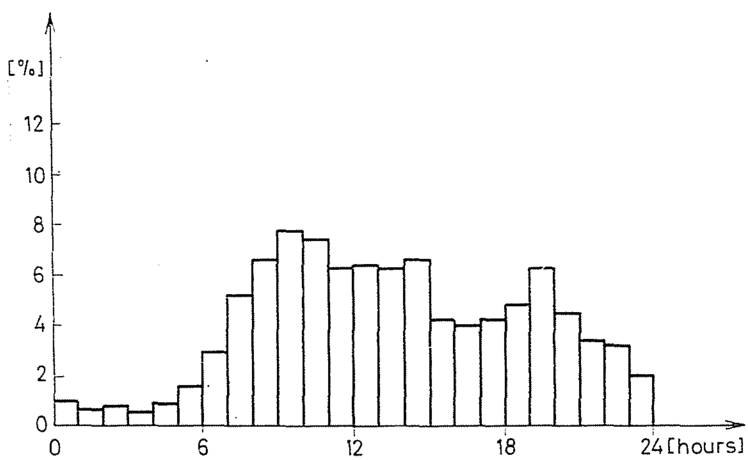

Fig. 4f. Pattern of the hot tap water consumption of a 100-flat block — on Sundays

period, hot water temperature moved at 70 to 75°C in those heat centres at which hot water temperatures were around 60°C on an average in normal operation as well. Accordingly, peak operation increased the hot water temperature by some 10—15°C, while at points where the hot water temperature never exceeded the 50°C figure, water demands could be met at a considerably higher temperature.

In large systems, due to the dissimilar distances between the power plant and the heat centres nearest to, and farthest from it, a two hours' shift occurred in the variations of water temperature. This, with pump induced circulation means that the accumulators can store significant amounts of heat to meet the evening peak of hot tap water demand, and the stored heat

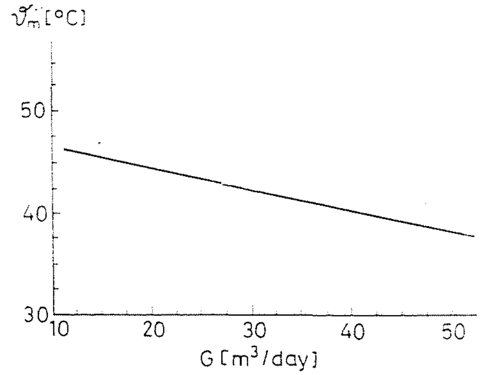

Fig. 5. Correlation of the temperature and quantity of hot tap water

of the later morning peak can be utilized advantageously in the lower daytime consumption, respectively in the early evening peak periods.

As a result of the dissimilar time pattern of the hot water consumption during the reference days, and the time shift due to the distances between the consumers, in the peak operation of hot water producing systems with accumulators, the better part of the excess heat is stored in the hot-water producing plant. Taking identical periods under normal operation or the average of the test day, this heat quantity is greater by 60 per cent.

The daily total heat yielded by the power station, in function of the ambient temperature, was the same as in normal operation, even on the test days, and also the ratio of heat used up to produce hot tap water to that used for heating, remained practically unchanged on the test versus normal operation days (Table 2), due to the fact that, what the consumers actually consume, is heat and not water. They need more of colder water and vice versa. This correlation has been indicated in Fig. 5.

This may have served as an explanation why the total daily heat quantity remains unchanged with higher hot tap water temperature during peak

Table 2

Date	Forward temperature of hot water in [°C]	Temperature of the thermal gradient temperature of hot water entering heating heat exchanger in [°C]	Return temperature of hot water in [°C]	Daily ratio of heat quantity spent on hot tap water and heat spent on heating	Ambient temperature in [°C]	Remarks
March 17	77	66.6	43	0.94	3.8	Peak operation
March 18	79	63	45	0.89	2.9	
March 19	78.5	62	45	0.97	3.8	
March 20	77	62	45	0.89	4.6	
March 22	72.5	58	42	0.91	9.7	
March 23	60.5	49	37.5	1.0	7.1	
March 24	67	53	39	1.0	3.8	
March 25	73	57	40	0.94	6.2	
March 26	68	53	39	1.07	7.9	
March 27	64	50	38	1.16	9.5	
March 28	63	50	37.5	1.04	10.1	
March 30	65	52.5	38	0.86	—	Normal operation
March 31	65	53	38	0.8	6.4	
April 1	65	53	39	0.86	8.1	
April 2	67	52	36	0.94	7.4	
April 3	67	52.5	37.5	0.965	5.9	
April 4	67	53	38.5	0.965	7.7	
April 5	66	53	38.5	0.9	6.4	
April 6	66	53	37.5	0.84	6.2	

operation. The consumer is supplied hot water at a higher temperature and this fact offers great advantages in certain types of running.

Between peak operations the lower daytime consumption was met from the stores of the "charged-up" transmission pipeline. This, prior to the evening temperature leap, cooled down the forward temperature of the hot water to around 50°C.

While it is not our intention to examine normal operation, we wish to call attention to the fact that even the low nighttime consumption may exhaust the accumulators and they become incapable, even with forced circulation, of covering the morning peak demand after the morning start. It would, therefore, be better to maintain circulation on the transmission pipeline after the cut-out of the heat supply, because this would enable the utilization of the substantial amounts of heat stored in the line and prevent the storages from cooling down.

In the hot water producing plants which have no accumulator facilities, the temperature of the forward hot tap water to the consumers is higher by 5—10°C than in the systems with accumulators. This is an important thing because, as proved by computer calculations, the design and building of hot water producing plants without accumulators is cheaper. This fact has been recognized also abroad and a breakthrough of such plants in Hungary may also be foreseen. With the peak operation of remote heating systems provided with accumulators, we may count only the thermal capacity of the transmission pipeline and the flats.

This is particularly so with farther lying accumulatorless hot water producers where from the heat produced in the late peak, the small consumption rate following the evening hot-water peak, will use only very little. In systems with accumulator facilities, there is a possibility to charge up the stores by pump induced circulation.

From the aspects of peak operation, therefore, distant consumers of hot tap water with power plants having no accumulator facilities, should be given consideration.

c) *Thermal losses of the pipework*

Perhaps the most difficult theoretical problem is to determine the heat losses of the pipework under the instationary conditions of peak operation. The mathematical processing of the problem is in progress but until a final

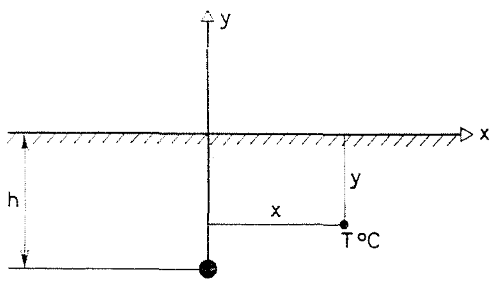

Fig. 6. Symbols

reply can be given, we have elaborated an iterative method, on the basis of an examination of the thermal losses on an electric model. While this examination, in the present form, is suitable for qualitative conclusions only, in a more developed form it may enable the numerical determination of the variations of thermal losses.

For starting we relied on [16] which presents the equations of the isotherms arising around a fictitious heat source in the ground (Fig. 6)

$$t = \frac{q}{4\pi\lambda} \ln \frac{x^2+(h-y)^2}{x^2+(h+y)^2} \quad [°C]$$

where

q — is the heat fed per metre and per hour in [kcal/m, h]
λ — the thermal conductivity of the soil in [kcal/m, h, °C], while for the designation of x, h, y see Fig. 6.

Introducing the designations:

$$\alpha = \frac{4\pi\lambda}{q}$$
$$C = e^{t\alpha}$$
$$C = \frac{x^2+(h-y)^2}{x^2+(h+y)^2}\,.$$

Deriving and arranging the equations we get:

$$x^2 + \left(y + h\,\frac{C+1}{C-1}\right)^2 = \left(\frac{2\,h\,\sqrt{C}}{C-1}\right)^2$$

which means that the isotherms assume the trend according to Fig. 7.

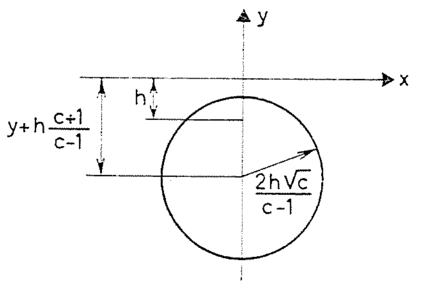

Fig. 7. Isotherms

Introducing the designations

$$z = \frac{\alpha t}{2}$$
$$\operatorname{th} z = \frac{e^{2z}-1}{e^{2z}+1}$$
$$\operatorname{sh} z = \frac{e^{z}+e^{-z}}{2}$$

the equation of the isotherms assumes the form:

$$x^2 + \left(y + \frac{h}{\operatorname{th}\frac{\alpha t}{2}}\right)^2 = \left(\frac{h}{\operatorname{th}\frac{\alpha t}{2}}\right)^2.$$

This equation is verified by another series of measurements, carried out for different purposes [18].

In 1967, the Municipal Remote Heating Works introduced a new method for the routing of heat transmission pipelines, according to which both the

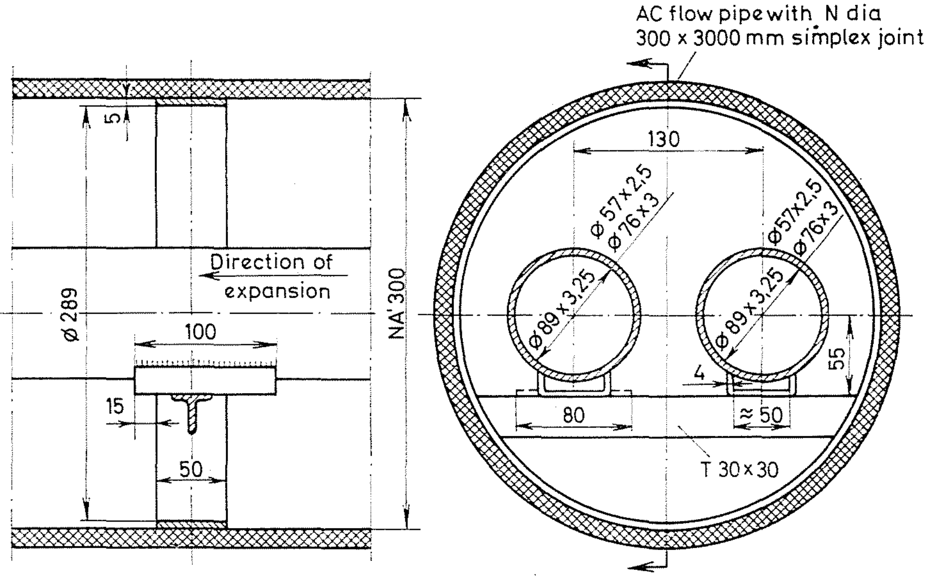

Fig. 8. Laying of transmission pipes with asbestos cement pipes

forward and return lines were laid in asbestos cement flow pipes without any insulations whatsoever, heat insulation having been provided by the air space between the hot water pipe and the asbestos cement pipe, while protection against moisture and high stability was ensured by the same asbestos cement pipe (Fig. 8).

The method is simple and ingenious; it needs very little in-situ fitting and groundwork.

Our task had been to examine the process from the aspect of thermal insulation, and to make a comparative study between the new and the conventional processes, from the aspects of economy. In the course of work, we elaborated a process for the measurement of the heat losses of heat transmission lines.

Brief description; measured data

α) Temperature distribution in the soil. Frames of 40/44 polyvinyl chloride tubing with insulation were applied around the line pair, with thermoelements fitted on the latter at predetermined points.

Earth was then filled back around the frames in the original situation, taking good care that the thermoelements should always be surrounded by earth and not by air.

The thermoelements were made with the soldering of copper constantane (FŐTÁM Laboratory), their wires laid into 110 polyvinyl chloride tubes and carried below ground level to the heat centre for the instrumental measuring and recording of the temperatures.

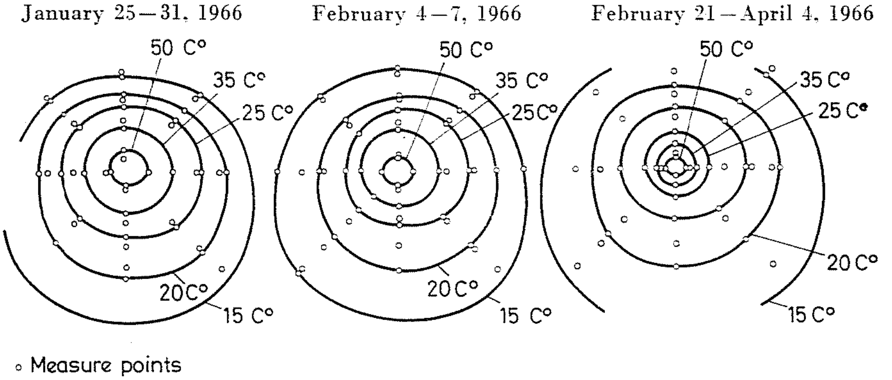

Fig. 9. Isotherms dia. 300 asbestos cement pipe without insulation

β) Measuring soil temperature. The original (not warmed up) temperature of the earth was measured at a suitable distance from the pipe, at depths corresponding to the points of measurement on the frame. The method applied was the same as used in the measurement of temperature distribution.

γ) Measurement of the ambient temperature. Ambient temperature was measured at 8—10 m from the buildings, and recorded by outdoor temperature recording instruments.

δ) Measurement of forward and return water temperature.

The temperature of forward and return water in the transmission line was measured in the heat centre by insulated thermoelements mounted on the pipes and checked by mercury thermometers.

For final conclusions the measured values were averaged.

The measurements were taken between January 26 and April 7, 1966. With the temperature frequency curves which embrace one half of the heating period, and with the second half being symmetric from the aspects of ambient temperature, it was possible to obtain a complete picture of the thermal losses over the entire heating period.

For the present examination only the temperature distribution curves were needed. A set of isotherms is shown in Fig. 9. The measurements enabled us to check on the accuracy of the previous correlations, on isotherms actually evolving around a circular heat source. Measurement and calculated data obtained from the measurements between February 4 and 17 in 1968 are compared in Table 3.

Table 3

Calculated radius				Measured radius	Deviation
t [°C]	$\frac{\alpha}{2}$	$\mathrm{sh}\frac{\alpha t}{2}$	$R = \frac{h}{\mathrm{sh}\frac{\alpha t}{2}}$ [m]	R_x [m]	Δ [%]
50	1.915	3.45	0.348	0.32	+ 8.75
35	1.34	1.778	0.676	0.788	−14.2
25	0.958	1.114	1.05	1.26	−16.65
20	0.767	0.84	1.43	1.805	−20.2
15	0.675	0.725	1.655	2.56	−34.0

Basic data for the calculation were:

$$q = 164 \text{ [kcal/m, h]}$$
$$\lambda = 1.0 \text{ [kcal/m, h, °C]}$$

The deviation may be due to two reasons: firstly to the error caused by the thickness of the lines in the charts (an 1/3 mm difference in the thickness of the line would cause an error of 4.16 per cent!). Secondly, we made examinations to find out at what thermal conductivity coefficient would the calculated data show agreement with the measurements.

Calculations, on the assumption of $q = 164$ kcal/m, h is shown in Table 4 below.

Table 4

t [°C]	$\mathrm{sh}\frac{\alpha t}{2}$	$\frac{\alpha t}{2}$	$\frac{\alpha}{2}$	λ/q	λ
50	3.75	2	0.04	0.00636	1.042
35	1.52	1.21	0.0346	0.0055	0.902
25	0.953	0.85	0.034	0.00541	0.886
20	0.685	0.615	0.0307	0.00488	0.800
15	0.479	0.46	0.0306	0.00487	0.800

The close on 20 per cent deviation in the assumed value of λ fully verifies the error.

This circular set of isotherms, which can be verified both theoretically and by measurements, was used in the preparation of the electric model. The earth mass around the pipes of unit length was divided into sectors (Fig. 10).

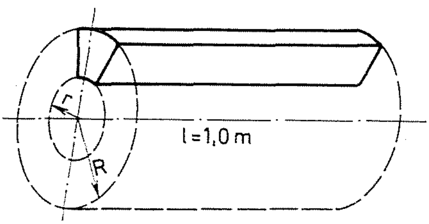

Fig. 10. Symbols

The heat resistance of each sector:

$$R_h = \frac{1}{\lambda l \alpha} \ln \frac{R}{r} \quad [\mathrm{m, h, {}^\circ C/kcal}]$$

$$l = 1.0 \ [\mathrm{m}]$$

its thermal capacity:

$$C_h = \varrho c V \ [\mathrm{kcal/{}^\circ C}]$$

where

V — denotes the volume of the sector in [m^3]
ϱ — earth density in [kg/m^3]
c — earth's specific heat [kcal/°C]

The conditions of the layout of the electric model are as follows:
similarity between heat conductivity and electric conductivity;
similarity between thermal and electric resistance;
similarity between thermal and electric capacity.

The electric quantities corresponding to the thermal resistances and thermal capacities:

$$\mathrm{h, {}^\circ C/kcal} \rightarrow [\mathrm{k}\ \Omega]$$
$$\mathrm{kcal/{}^\circ C} \rightarrow [\mu\mathrm{F}]$$

whence the time transformation:

$$1 \text{ hour} \rightarrow 1 \ \mu\mathrm{s}$$

Accordingly, the electric model of one sector is as shown in Fig. 11.

Dividing the earth mass surrounding the pipe of unit length into forty sectors, we arrive at the electric layout seen in Fig. 12, where the digits stand for the number of sectors.

The arrangement being symmetric, it is sufficient to model one half only. Two different measurements were carried out on the model:

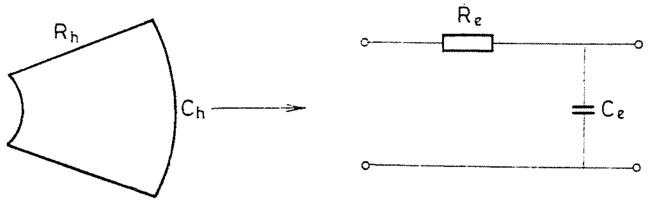

Fig. 11. Symbols

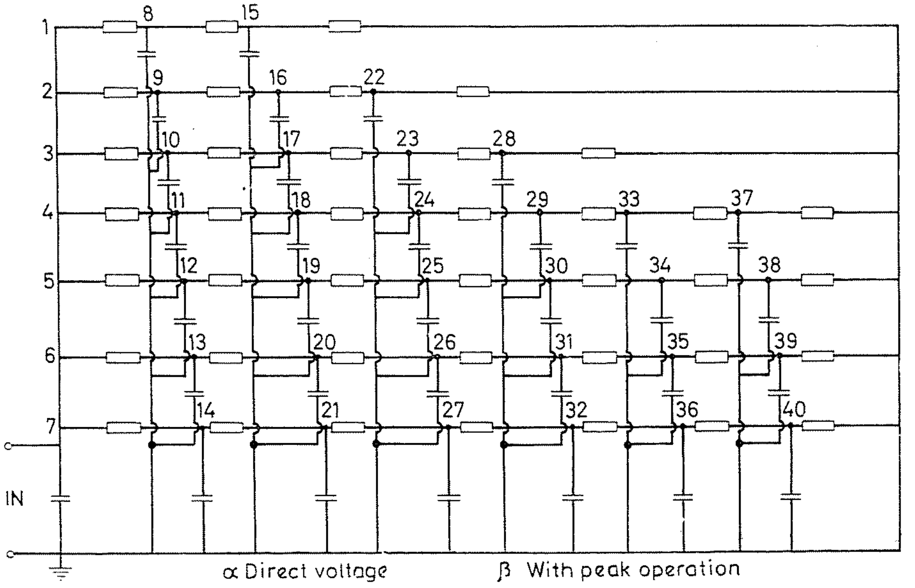

Fig. 12. Temperature of the earth surface 0°C within a circle of a radius of R = 5 m from the centre of the pipe, temperature drops to 0°C. Increasing temperature from the earth surface downwards has not be taken into consideration

α) In stationary operation, the temperature of water flowing in the pipe is constant in time (such case had been tested so far by measurements and calculations). This corresponds to direct voltage. Measurements results are shown in Fig. 13. The isotherms show a fair degree of agreement with the above measured and calculated values.

β) In peak operation, the liquid flowing in the pipe varies according to the periodic time function. A rather extreme case was taken for the example:

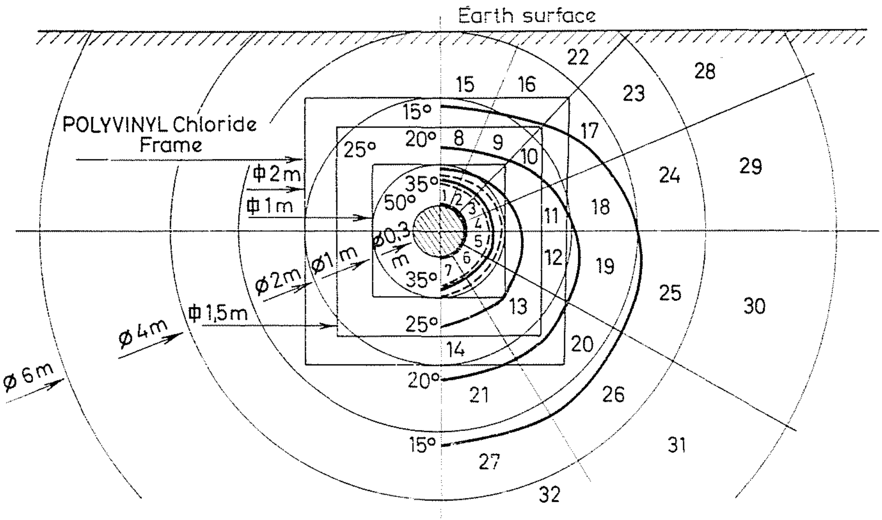

Fig. 13. Isotherms

positive peak operation with a maximum difference between maximum and minimum temperatures of 50°C, and with 2 times 4 hours of peak operation (Fig. 4/a), to examine the effect of peak operation upon thermal losses under

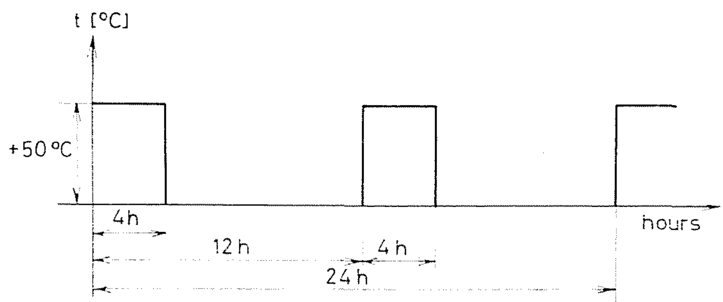

Fig. 14a. Patterns of peak operation

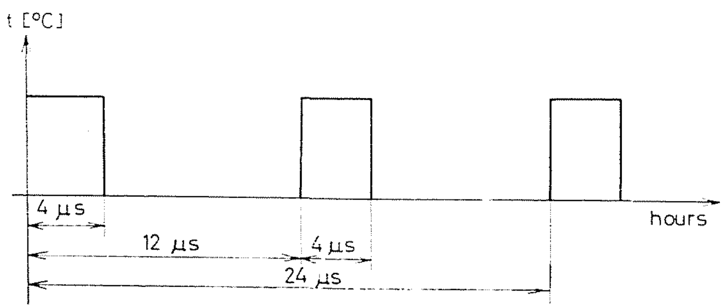

Fig. 14b. Patterns of peak operation

the possibly most adverse circumstances. The time function of peak operation converted to electric time function is shown in Fig. 14/b.

The findings of the model experiments and measurement on peak operation show that deviations in the isotherms occur only in the innermost circle, while farther outward, the isotherms remain unchanged. The conclusion — for the time being qualitative only — may be drawn, therefore, that peak operation has very little effect on the thermal losses of the transmission pipelines.

It is, therefore, obvious and provable both principially and theoretically, that operation according to the time function of peak operation causes no excess heat loss. The numerical evaluation and processing of the problem is actually in progress.

Author would note — regardless of peak operation — that the examination method with the set of isotherms has not only led to numerous interesting findings, but pointed towards an entirely novel process for the measurement of heat losses which, however, cannot be described here for lack of space.

Summary

Changes in the structure of energy carriers and fast technical development have introduced new concepts in the building and running of heat supplying power plants.

A new and modern method for operation is the running of heat producing power plants during the electric peak periods. The paper deals with the indications, methods and potentials of electric peak operation, as well as the problems caused by peak operation from the consumers' angle.

In this framework, author examined the trends in the temperature inside flats, the pattern of the temperature of hot tap water and the heat losses of the transmission pipelines.

The examinations were performed through measurements (Part I) and theoretical deliberations (Part II). Both methods have proved that peak operation has no contraindications from the consumers' standpoint, and the pontential economic advantages may, and should be exploited.

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