EFFECT OF LIQUID TEMPERATURE ON THE HYDRAULIC PERFORMANCE AND THE VIBRATION OF CENTRIFUGAL PUMPS

By

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1. Abstract:

This research is the second one of a set aims to have some informations about the hydraulic and vibration performance of centrifugal pumps under the different operating conditions.

This research was planned to investigate the vibration characteristics of the pump performance and the effect of the pumped water temperature on it's level.

2. Introduction:

The vibration of moving or rotating parts of any machine has some harmfull effects. One of these effects is the failure of machine parts. Another effect is the noise leading to discomfort.

It is a matter of importance that the pump may operate at different water temperatures according to the water supply nature (width, depth, water velocity ... etc).

This work is carried out to investigate the vibration characteristics of a pump and its performance under water temperature variation.

The fluid used in the experimental work is the drinking water at 20° & 45° and 60° degree centigrade.

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3. Nomenclature:

A : Mean amplitude of vibration (μ.m.PK-PK),
A_x : Mean amplitude in X-direction,
A_y : Mean amplitude in Y-direction,
F : Spring balance force (gm),
H : Total head (m.H_2O),
H_d : Delivery head (m.H_2O),
H_s : Suction head (cm.Hg),
L : Torque arm (0.18 m.),
N_m : Motor horse power,
N_w : Water horse power,
n : Revolutions per minute (R.P.M),
Q : Rate of flow (lit/sec.),
γ : Specific weight (Kg/m^3),
η : Efficiency.

Subscribts:

$(\quad)_s$: Suction side.
$(\quad)_d$: Delivery side.

4. Sources of Vibration in Centrifugal Pumps Installations:

In addition to the mechanical sources of vibration and noise in centrifugal pumps as dynamically, operated machine, there are other sources of noise and vibration. These sources may be one or more of the following:

a) Cavitation[1,2,3]
b) Separation[4]
c) Turbulence[5]
d) Pumping system[6]

Each of all the above mentioned parameters affects the resultant pump's vibration.

But the variation of the pumped water temperature is of a great importance in determining its physical properties, which directly affect the hydraulic performance of the pump. Theoritical calculations of the hydraulic performance curves for centrifugal pumps are still far away from the actual ones. The sofisticated flow charecter in centrifugal pumps led to the well known approach of the experimental hydraulic performance.

In the same time the vibration of such a complicated system is very difficult to study theoritically. No attemp was done, except (6), to give such information. So, the approach to this problem is, by necessity, experimental for both the hydraulic and vibrational performance of pumps.

This work is devoted to clarify the vibrational performance under different water temperature.

5. Experimental Work:

The arrangement of the system used for these investigations is shown on Fig. (1). It consists of the tested model pump, main supply tank, three electric heaters with thermostats, collecting tank, and measuring instruments.

The specifications of the tested pump are:
Power : 1.36 H.P, Revolutions per minute : 3000, Suction diameter: $1\frac{1}{4}''$, and delivery diameter $1\frac{1}{4}''$.

The water temperature was controlled by the thermostats and was measured by a mercury in glass thermometer with 0.5 degree centigrade accuracy.

The flow rate was measured through the collecting tank using a stop watch. The allowable time error, for the human response is 0.3 sec.

The suction head was measured by a calibrated vacuum meter with accuracy ± 0.5 centimeter mercury.

A calibrated gauge with accuracy ± 0.25 meter of water was used for measuring the delivery head.

To obtain the motor horse power; the mechanical arrangement shown on Fig. (1) was used. It consists of a calibrated spring balance, and mechanical tachometer. The accuracy of the spring is ± 20 grams, meanwhile the tachometer's accuracy is ±25 R.P.M.

A portable vibration analyser model 2100, was used with AV 100 P accelerometer to determine the mean amplitude of the vibration in the two perpendicular directions on each suction and delivery sides.

The amplitude waves were recorded by a chart-recorder connected with the analyser.

All the measured amplitude values were in the wide band frequency of 10-1000 H_z.

The calculations procedure was as follows:

* Total head $H = H_s(\text{cm.Hg}) \times 0.13595 + H_d(\text{m.}H_2O) \ldots (\text{m.}H_2O)$ ....(1)

* Flow rate $Q = \frac{91.698}{t}$ (Lit/sec.) ....(2)

Where t is the required time in seconds for collecting a pure height equal 30 centimeter of water in the collecting tank which has an inner area equal 0.30566 squared meter.

* Water power $N_w = \frac{\gamma \times H \times Q}{75}$

or $N_w = \frac{H \times Q}{75}$ (H.P) ....(3)

Since = 1 kg/Lit.

* Motor power $N_m = F(g) \times L \text{ (meter)} \times \frac{2\pi n}{60} \times \frac{1}{75000}$

or $N_m = (2.5132 \times 10^{-7}) \times F \text{ (gm)} \times n \text{ (R.P.M)}$ ....(4)

* Over all efficiency $\eta = \frac{N_w}{N_m}$ .....% ....(5)

* Mean amplitude $A_m = \frac{A_{max.} + A_{min.}}{2}$ (μm) ....(6)

The accuracy of the collected data were calculated and found to be;

$H = H \pm 5\%$

$Q = Q \pm 2\%$

$N_w = N_w \pm 7\%$

$N_m = N_m \pm 4.8\%$

$\eta = \eta \pm 2.2\%$

$A_m = A_m \pm 3.3\%$

6. Discussion:

Figure (2) shows the (H-Q) curves for the investigated centrifugal pump (the model) at 20,45 and 60 degree centigrade. It can be seen that the increase of water temperature, leads to decrease of the maximum achieved discharge. This is connected with the fact that viscosity of water decreases with the temperature increase. At higher temperature, leakage increases, since viscosity decrease, meanwhile the friction losses decrease. The volumetric efficiency decreases and even the achieved total head decreases.

At low flow rates, it was noticed an increase of the total head at higher temperatures. The deviation is within the accuracy of the experiments.

The (N-Q) curves for the pump are shown in Fig. (3). The power is a linear function of Q. This feature is kept within the experiments accuracy.

Fig. (4) shows (η-Q) curves. The drop of efficiency at high flow rates for the case of high temperature is connected with the drop in the volumetric efficiency due to the decrease of viscosity. At lower flow rates, the increase of efficiency at higher temperature is connected with the deviation in motor power (Fig. 3).

The main tendency of (A-Q) curves (for example, Fig. 5) is that the amplitude around the nominal flow rate has an initial value. Departure from the nominal flow rate, in direction of higher or lower values, leads to increase of the amplitude. At higher flow rates, the amplitude is fluctuating. The level of the amplitudes for this region is higher than its nominal value.

Decreasing the flow rate from the nominal value, the amplitude increases, not reaching so high values as on the other side of the nominal regime. Further decrease of rate of flow leads to decrease of the amplitude with a limited number of peaks.

Figure (5) shows (A-Q) curves at suction side of the pump in X-direction (refering to Fig. 1).

It is noticed that the noise in the system in condition of test is below 0.2 μ.m. Operating the pump at no discharge, the amplitude rises up to (5 μm.). As soon as the delivery begins, the amplitude decreases sharply reaching a minimum value, after which it begins to increase. This is connected with the fact that at very small flow rates, the attack angle is large. Separation of flow in this condition is probable. Beginning from zero, a small increase of flow rates dictates better conditions for flow, hence, amplitude decreases. The kinetic energy of the vibrating mass is still decreasing, since the mass is small, till a certain point at which the kinetic energy begins to increase on account of the increasing mass.

The amplitude continue increasing, with a different rates, with the flow rate increase. Approaching to the nominal operation conditions, the amplitude tends to decrease, owing to the fact that in nominal operating conditions, the attack angle is almost zero or its nominal value, where separation intensity is minimum.

Further increase of flow rate more than its nominal value, leads to increase of attack angle in opposite direction. This leads to bad flow conditions on the front surfaces of blades and better flowing conditions on the rear surfaces of the blades. Possibility of separation on the back surface is always more. So, a small deviation from the nominal conditions leads to a greater increase of separation intensity, which means a higher levels for the amplitudes. Further increase of flow rates leads to fluctuation of the amplitude. This may be connected with the natural frequencies of the system.

Amplitude-suction head curves on Fig. (6) are the same as on Fig. (5), but instead of Q, it was plotted the measured suction head. Since, the suction head is an increasing function of (Q), the form of ($A-H_s$) curves is the same as (A-Q) with scale modification.

The amplitude of vibration on the suction side in the Y-direction is shown in Figs. (7 & 8). The main tendencies are the same for the X-direction vibration. The levels of both are of approximately the same amplitude. The number of peaks is also the same.

The performance of vibrations amplitude on the delivery side is some what different (Figs. 9, 10, 11, 12). In X-directiont the amplitude, at lower than the nominal flow rate, is higher than that on the suction side in the same working conditions.

As can be seen from Figs. (5),(7) and (11), the main tendency is that increasing temperature, the amplitude level tends to decrease. The minimum level was noticed to be at 45°C. Further increase of temperature leads to increase the amplitude. This rule is holding true for all measurements except for the case of the X-direction amplitude on the delivery side Fig. (9), in which the level of 20°C is the highest.

From general position, increase of temperature leads to change of physical properties of water. More exactly, viscosity decreases and specific volume increases.

We believe that the energy of vibration is in opposite proportion with the specific volume. Damping effect is also in opposite proportion with the temperature. It can be assumed that the rate of damping is high enough at lower temperature. So beginning with an initial level at 20°C, with the increase of temperature, the damping rate is greater than the decrease of the kinetic energy of vibration. This means a lower level of the amplitude.

Further increase of temperature leads to more decrease of the damping effect meanwhile the change in energy is nearly the same, so the amplitude of vibration, reaching minimum, begins to increase with increase of temperature.

The unusual case of X-direction on the delivery side, laying off of the previous imagination, needs an explanation, which we can't give in this work.

7. Conclusions:

1. The effect of temperature of fluid on the amplitude of vibration is different acoording to the temperature difference. Increasing the temperature to a certain limit, leads to decrease of the amplitude reaching a minimum value. Further increase of temperature leads to increase of the amplitude.
2. In this work, the recorded vibration is mainly due to separation, turbulence, and mechanical vibration of the system elements, but not due to cavitation, since the minimum achieved suction pressure is still faraway from the vapour pressure corresponding to the prevailiing temperature.

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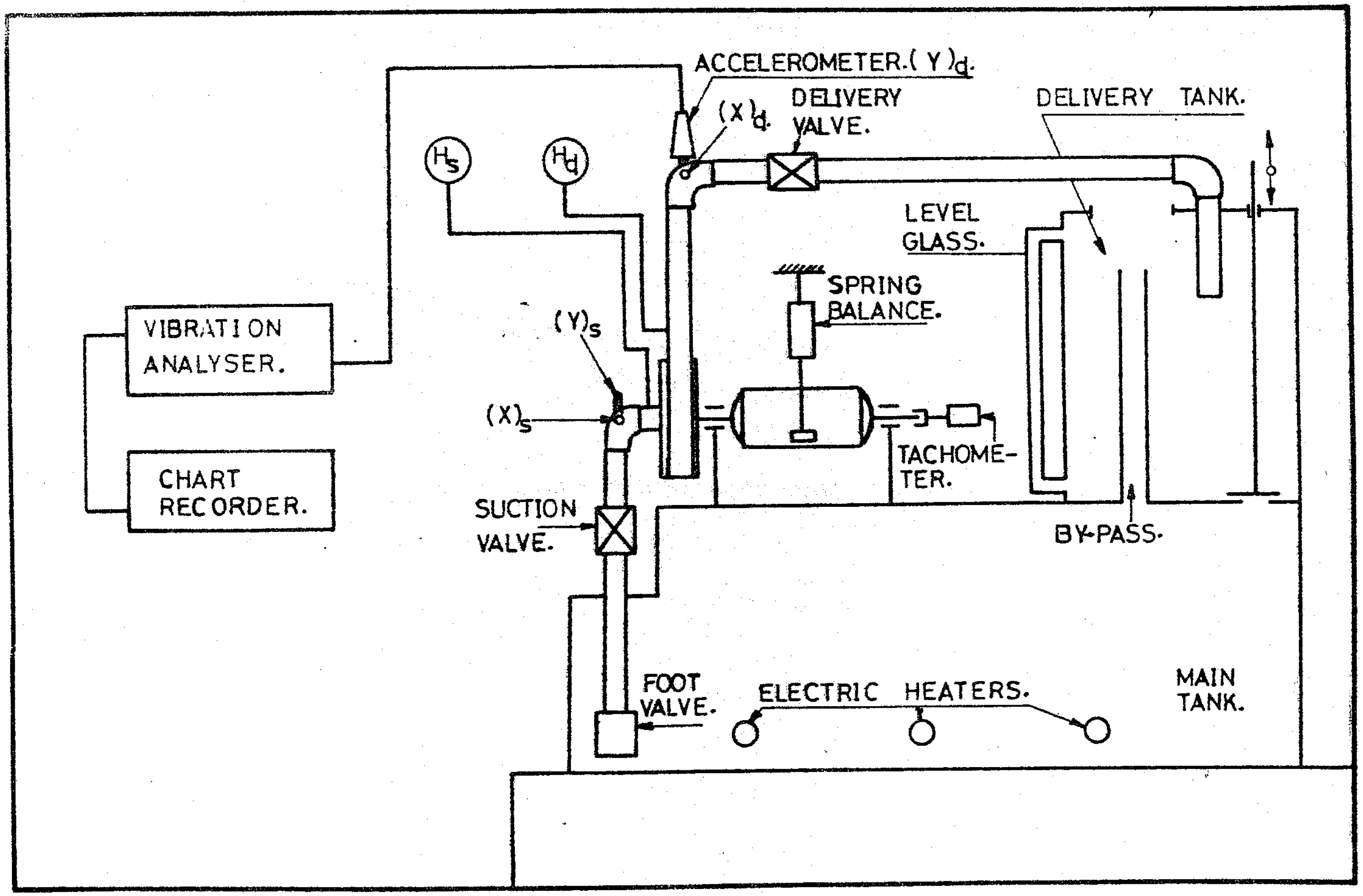

Fig. (1). Arrangement for testing the pump.

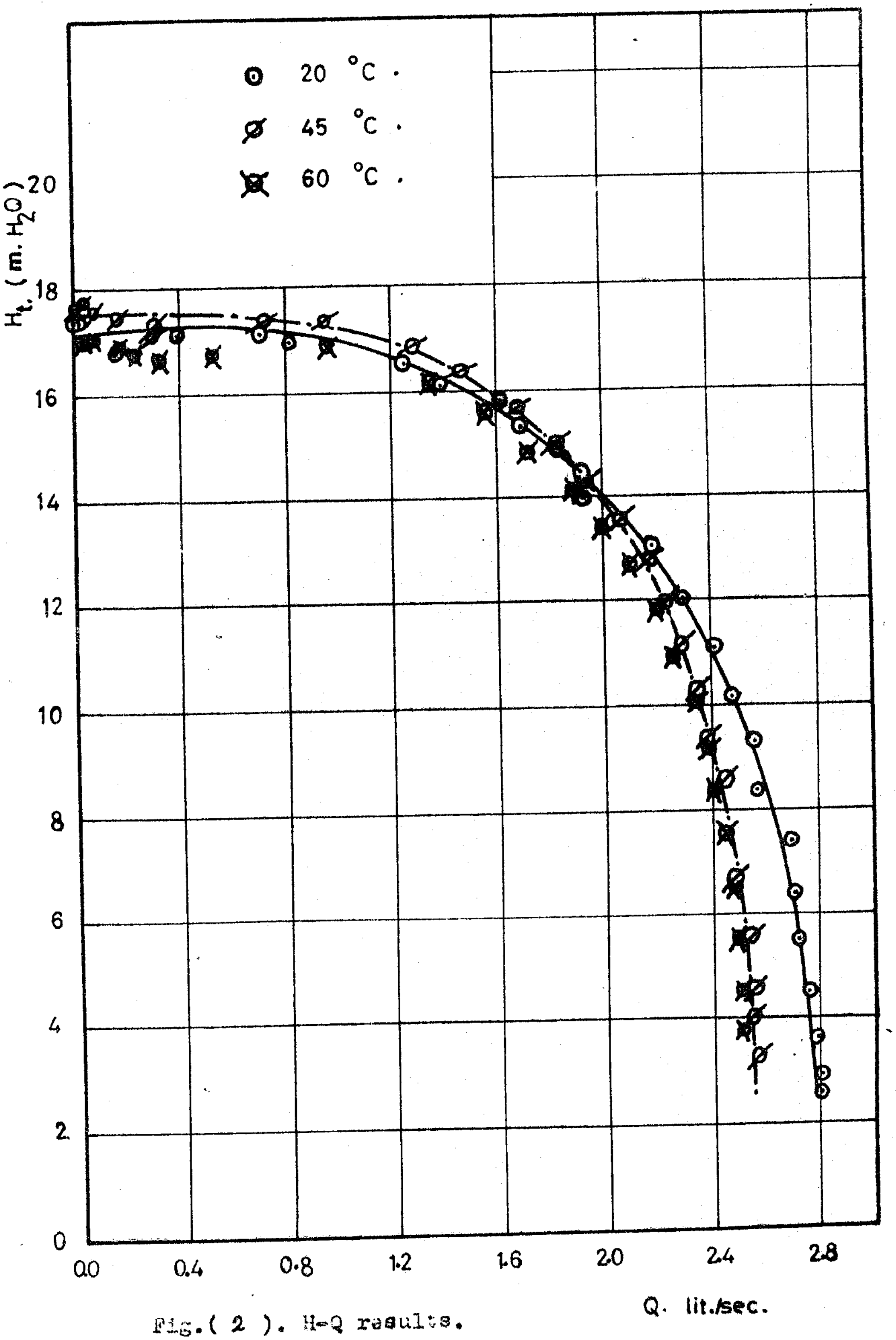

Fig.(2). H-Q results.

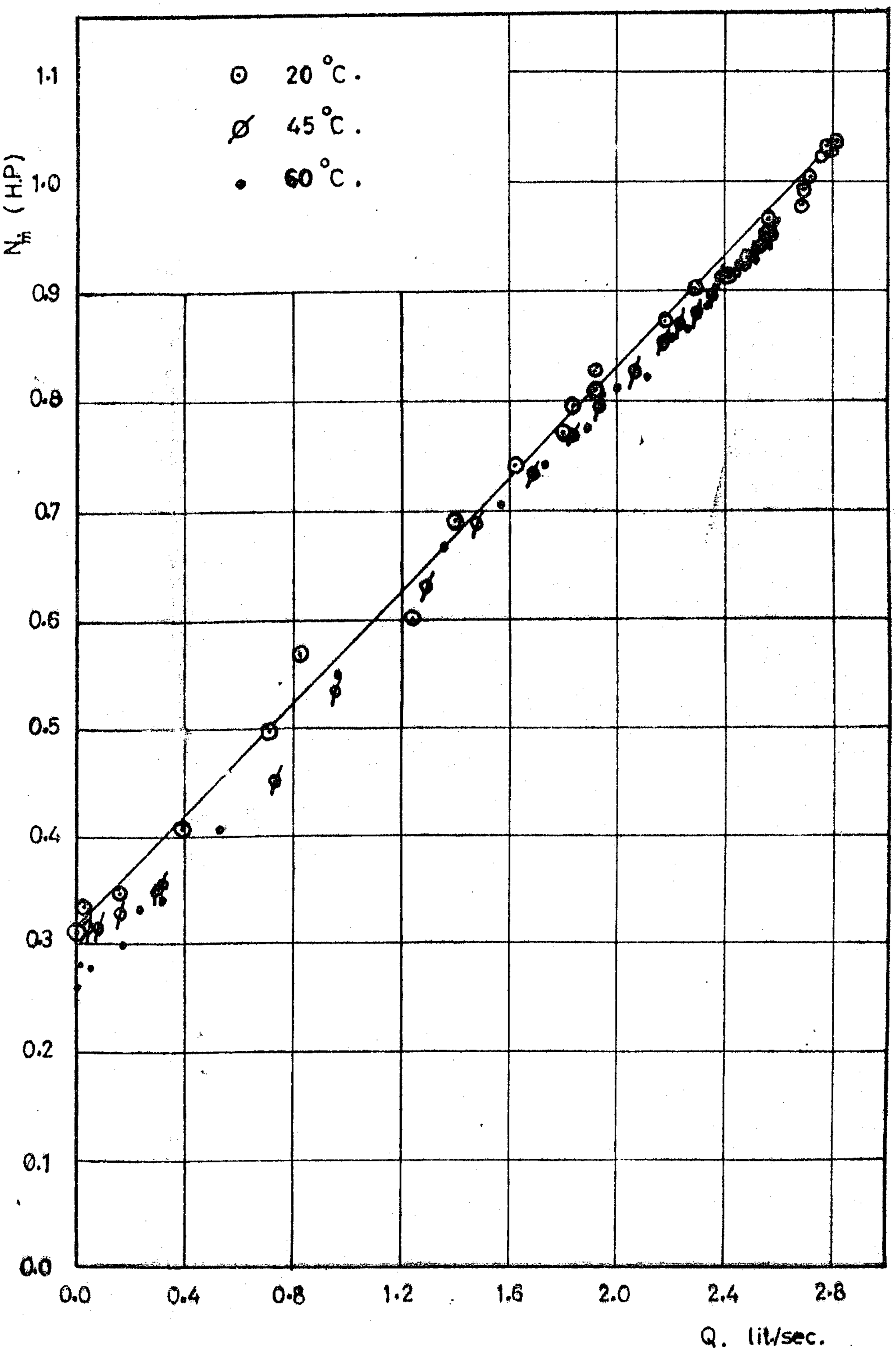

Fig.(3). N_m-Q results.

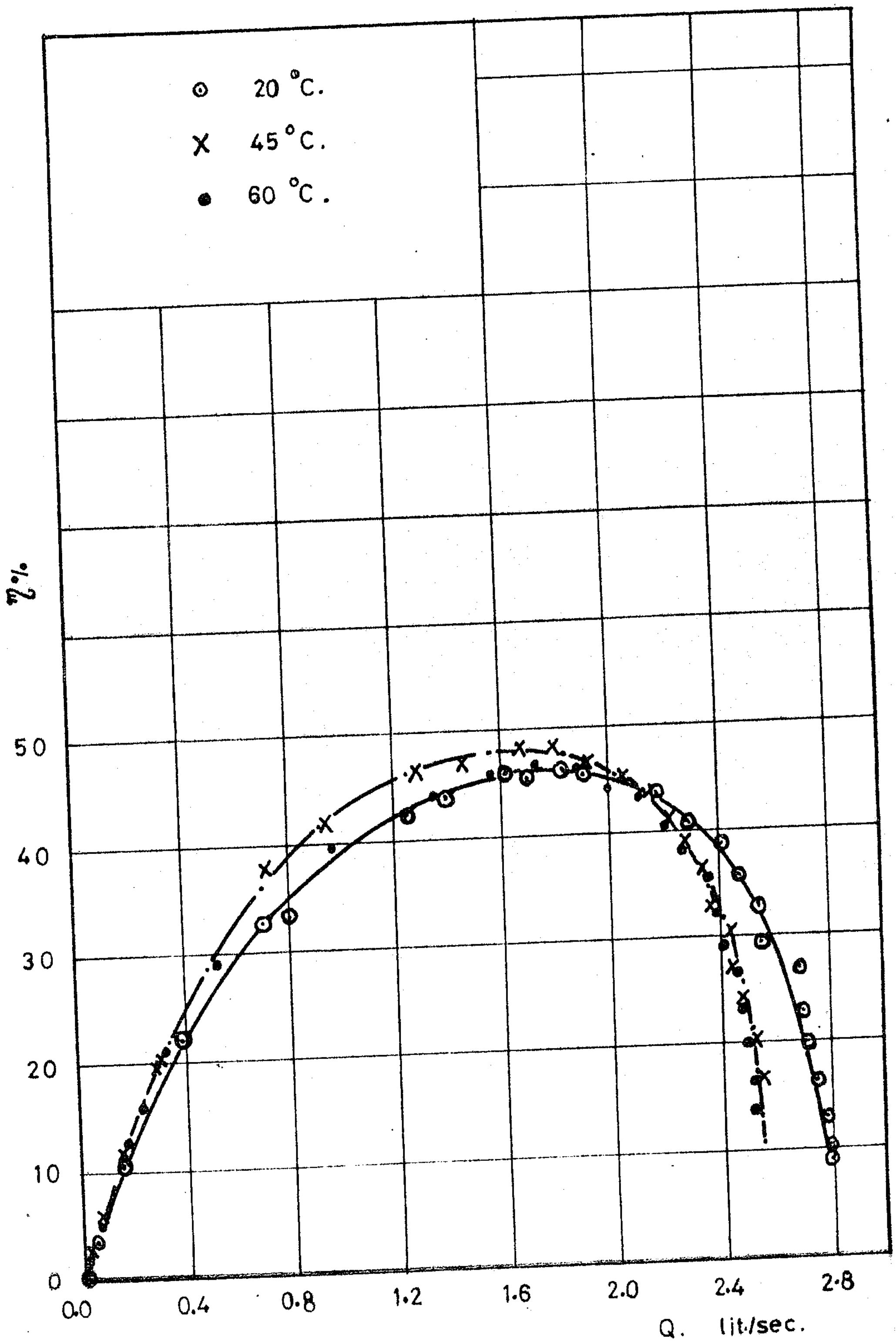

Fig.(4). η -Q results.

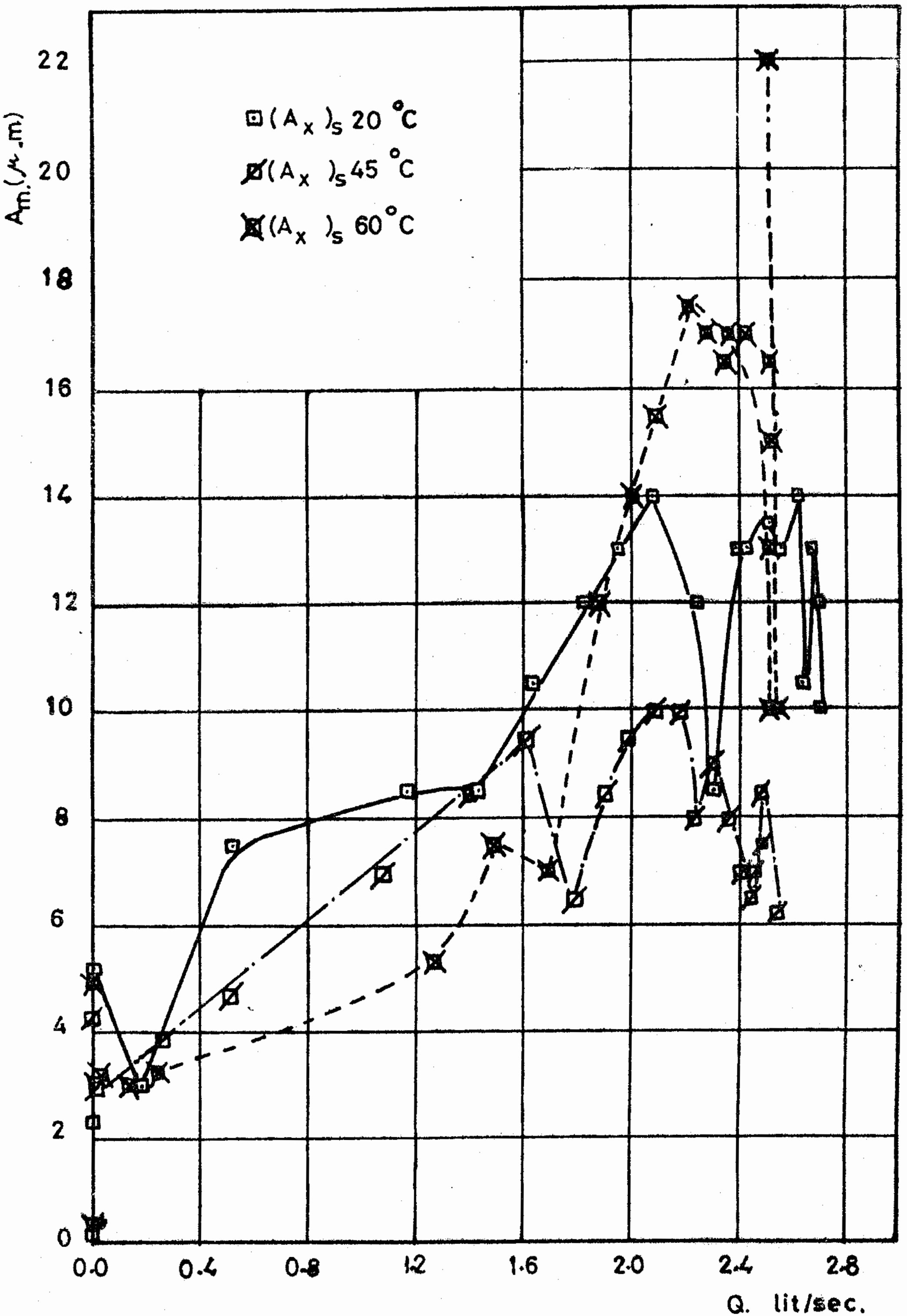

Fig.(5). A-Q result in x-direction on suction side.

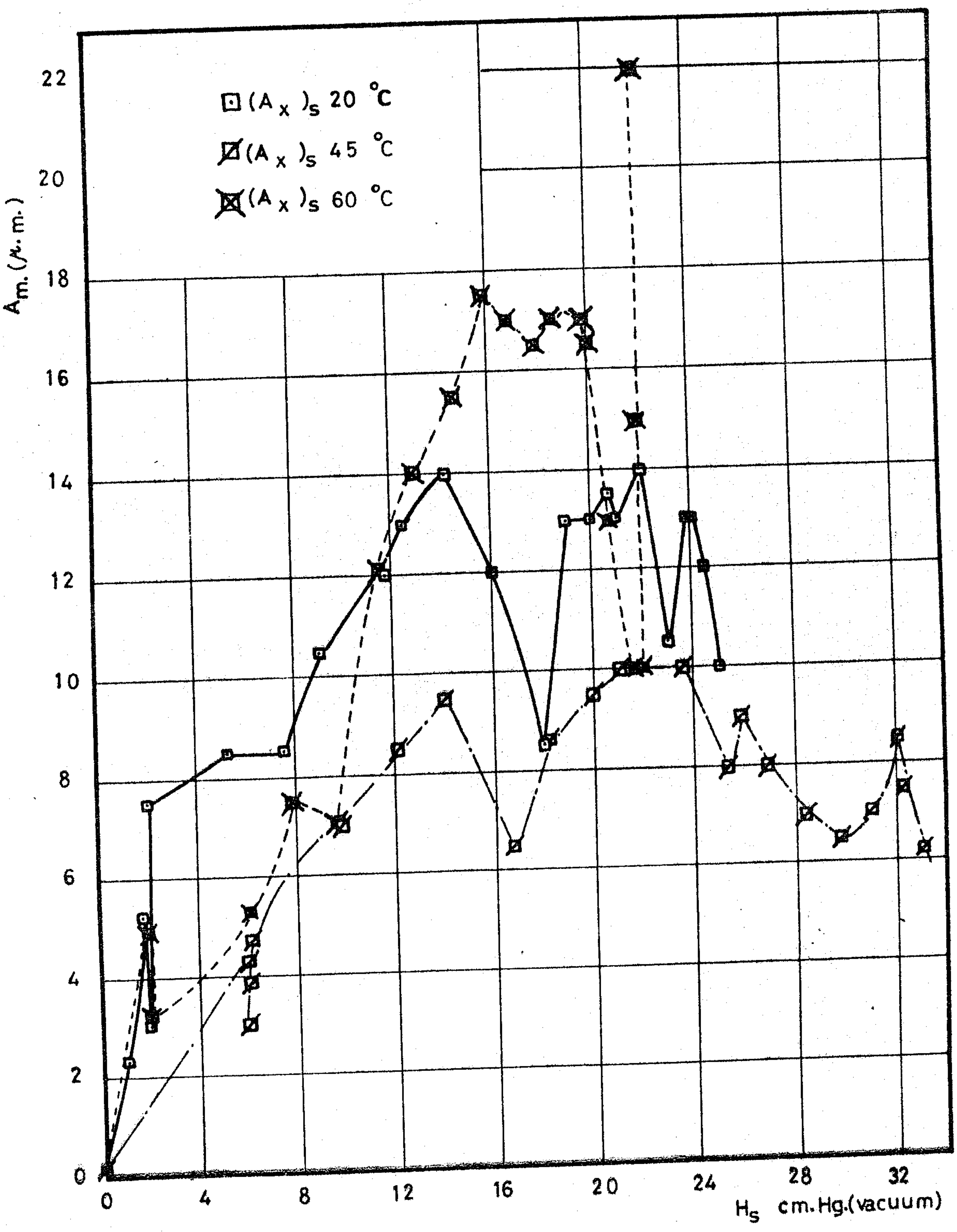

Fig.(6). A-H_s results in x-direction on suction side.

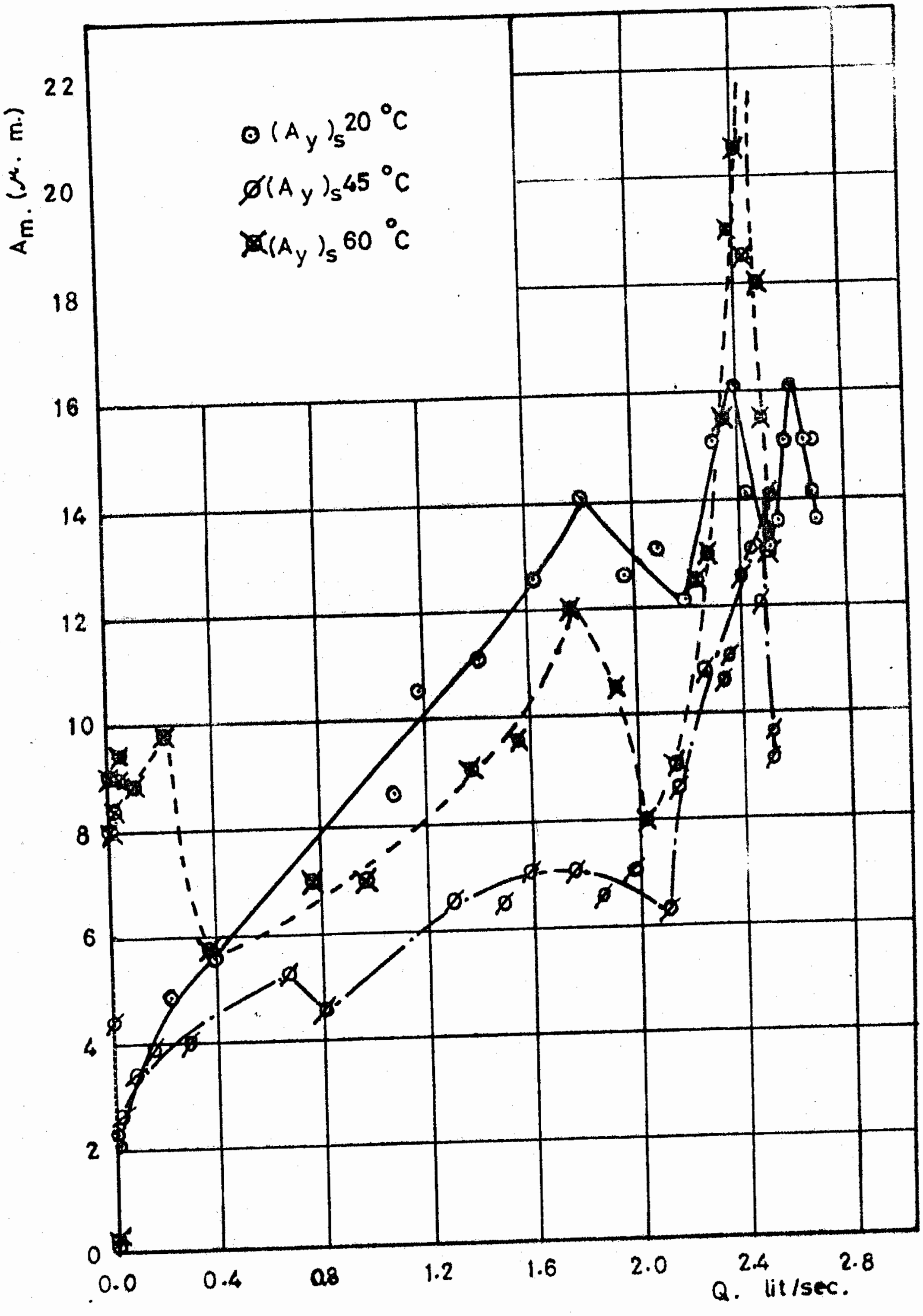

Fig.(7). A-Q results in y-direction on suction side.

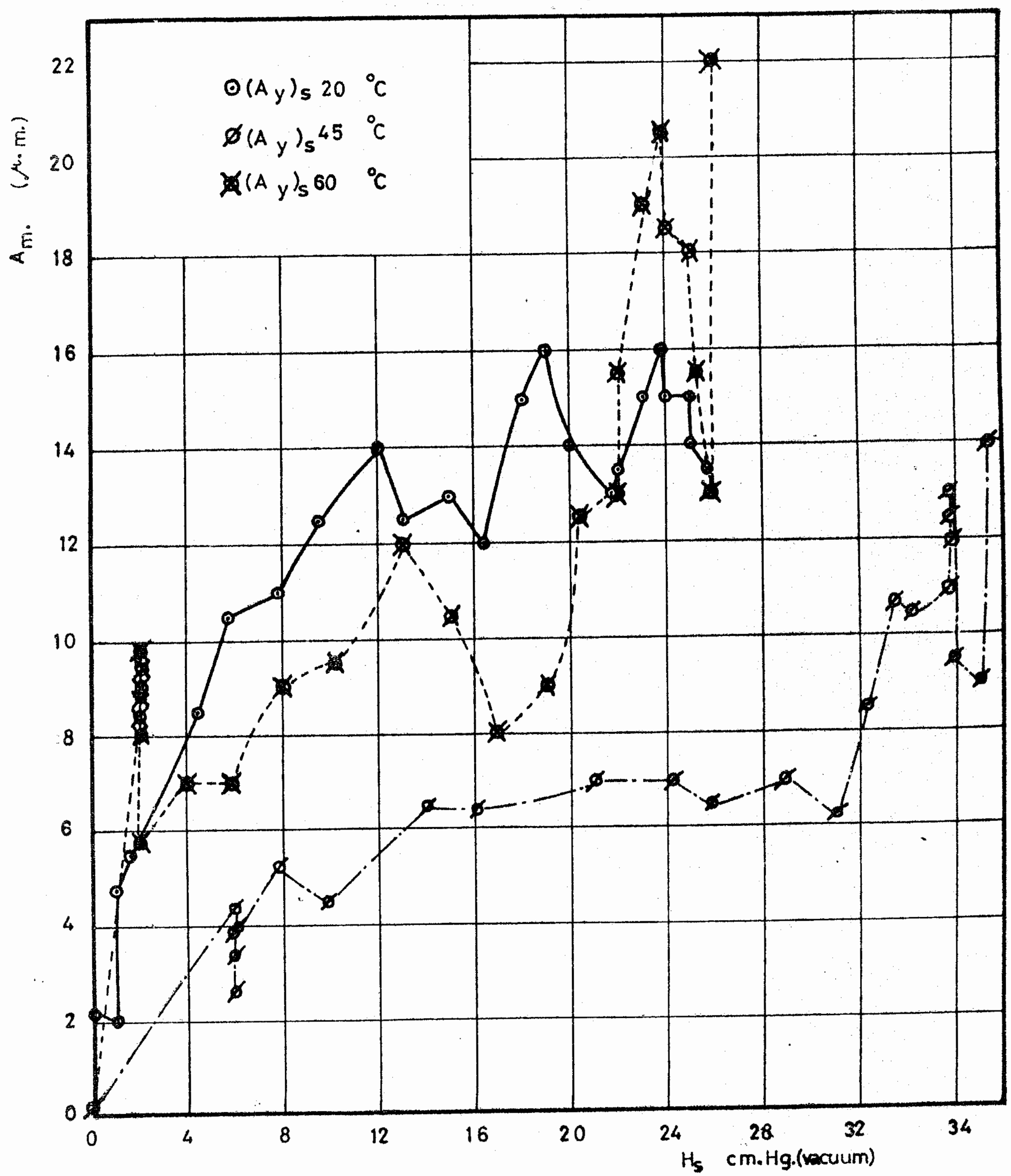

Fig.(8). A-H_s results in y-direction on suction side.

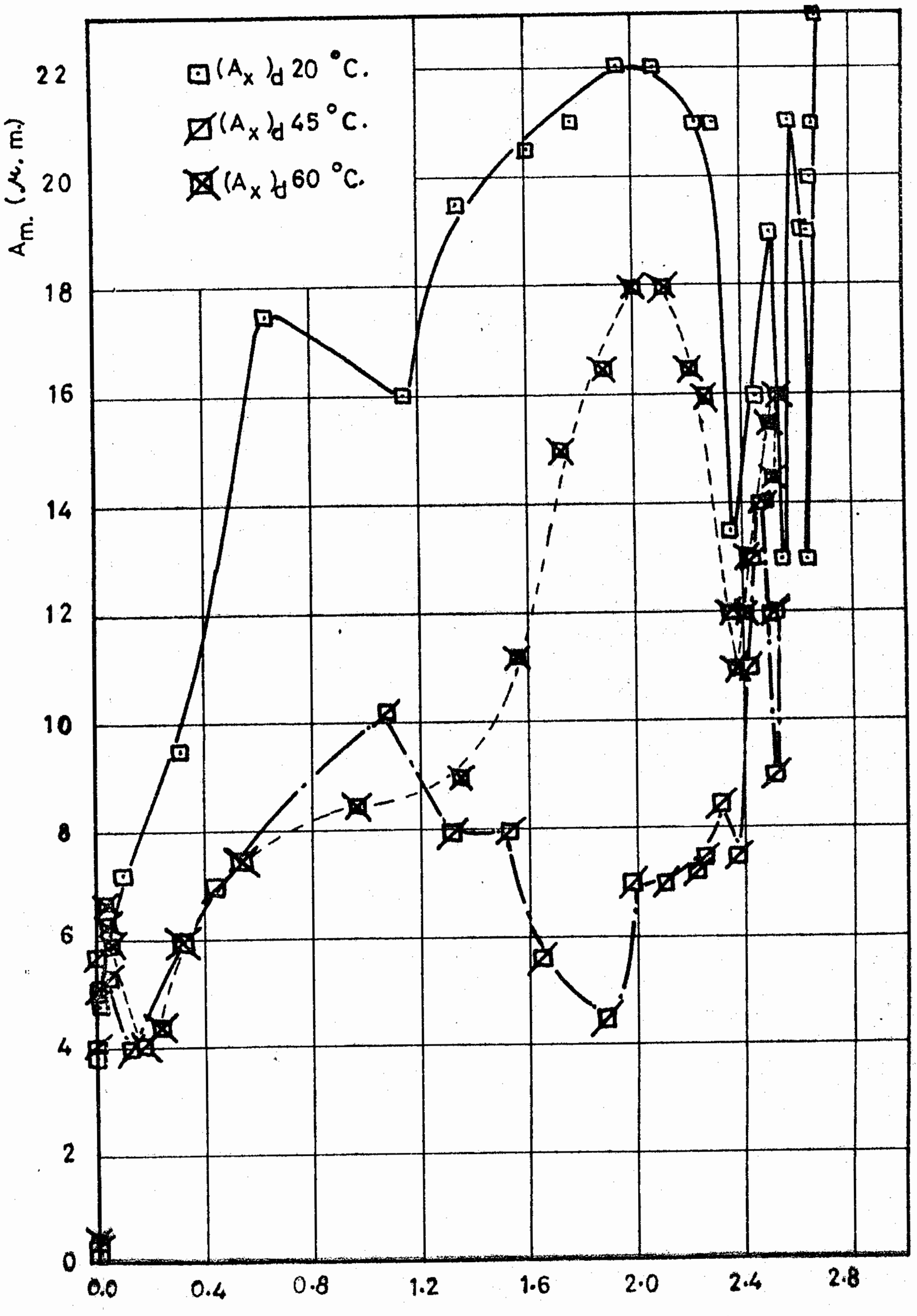

Fig.(9). A -Q results in x-direction on delivery side.

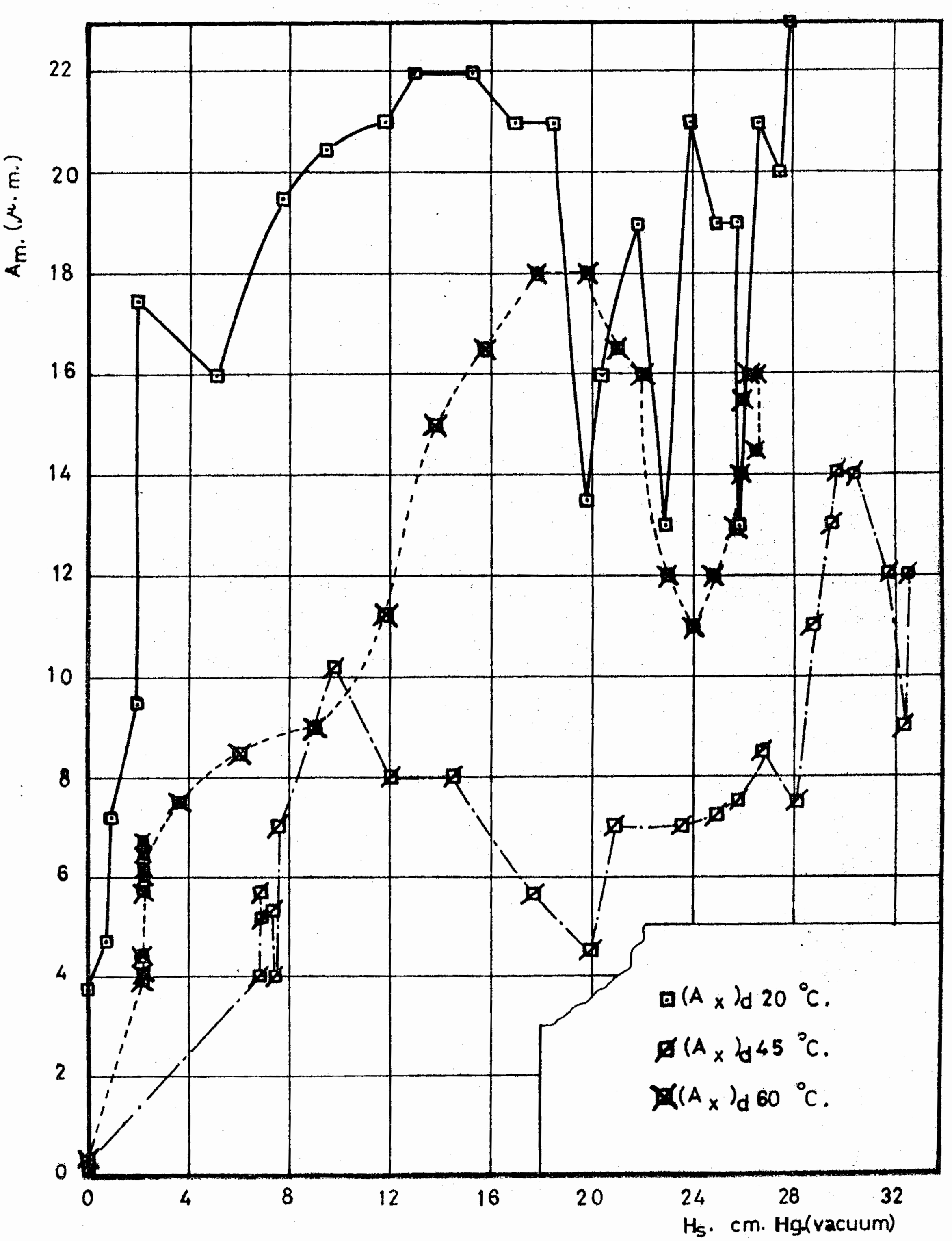

Fig.(10). A-H_s results in x-direction on delivery side.

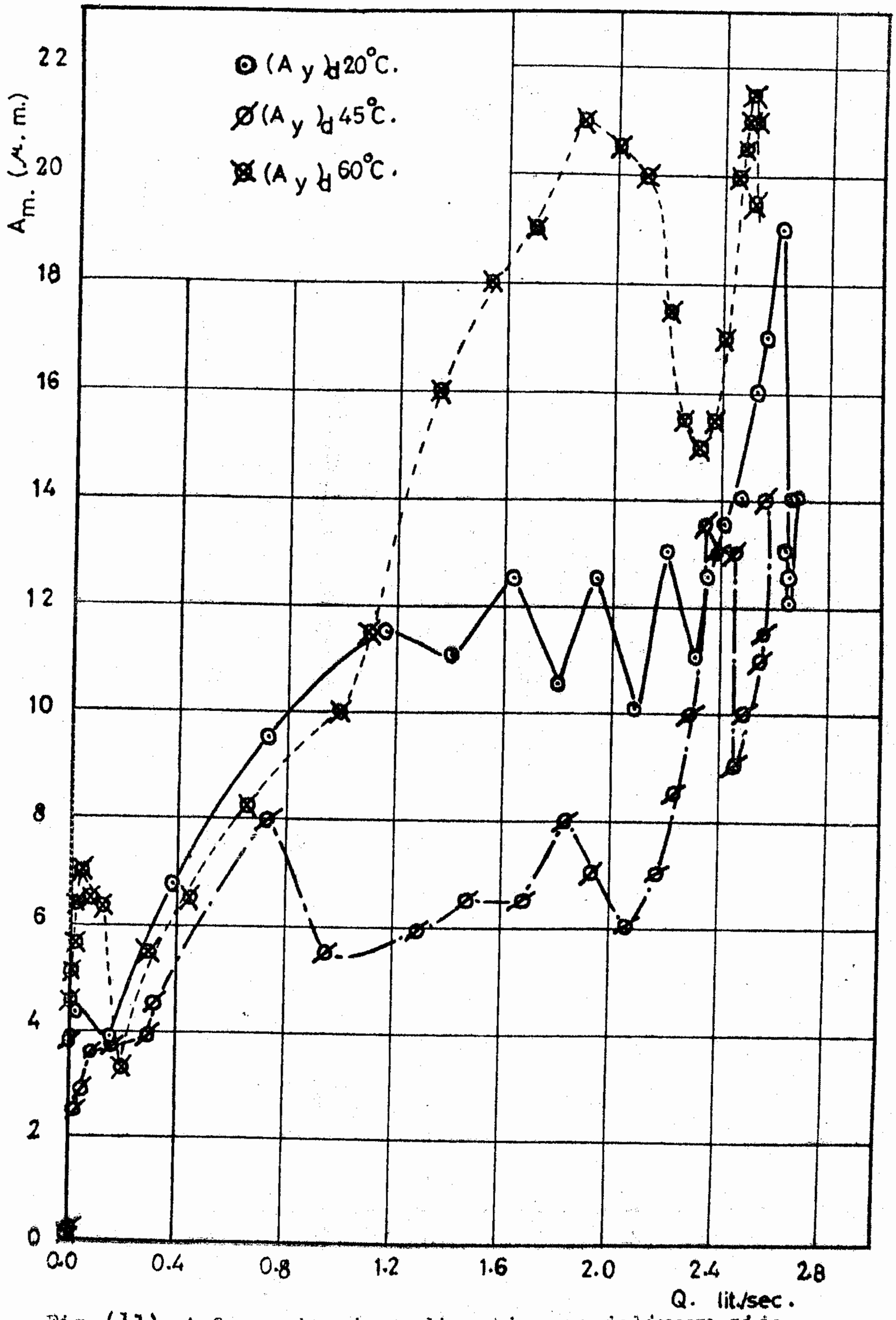

Fig. (11). A-Q results in y-direction on delivery side.

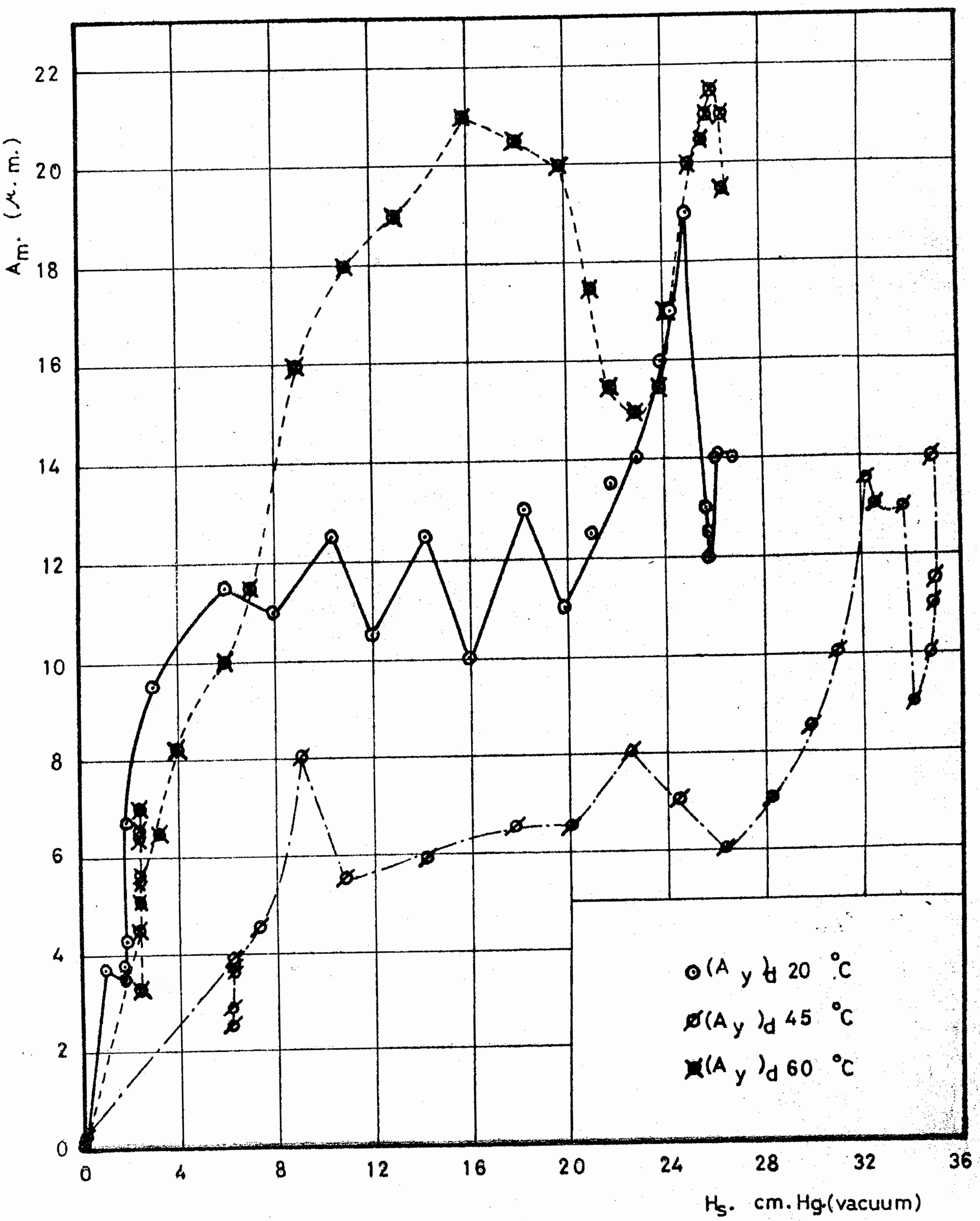

Fig.(12). A-H_s results in y-direction on delivery side.

أثر درجة حرارة السوائل على الاداء الهيدروليكى واهتزازات مضخات الطرد المركزى

يعتبر هذا البحث هو الثانى فى سلسلة من البحوث تستهدف الحصول على المعلومات عن أثر درجة حرارة المياه التى يتم ضخها على كل من :

١ ـ خصائص الاداء الهيدروليكى .

٢ ـ اهتزازات المضخه .

وذلك نظرا لما لدرجة الحرارة من أثر متوقع على اداء المضخات الطارده المركزية .

ونظرا للصعوبه البالغة فى معالجة هذه المسألة نظريا فقد تم ترتيب أجراء تجارب لقياس سعة الاهتزازات فى نقط على جانبى السحب والطرد عند درجات حراره ٢٠ ، ٤٥ ، ٦٠° مئوية بواسطة محلل اهتزازات نقالى كما أمكن تسجيل سعة الاهتزازه كداله فى الزمن باستخدام مسجل ورقى Chart-recorder هذا بالاضافة الى تحديد الاداء الهيدروليكى ممثلا فى منحنيات معدل التصرف ـ الضغط (العلو) ، معدل التصرف ـ القدرة ، معدل التصرف ـ الكفاءة .

وقد أوضحت النتائج المعمليه التى يتم الحصول عليها لاول مرة أن سعة الاهتزازات على جانبى السحب والطرد تتغير تبعا لظروف التشغيل ودرجة حرارة المائع اذ أن سعة الاهتزازات تقل بازدياد درجة الحرارة حتى ٤٥°م حيث بعدها تبدأ فى التزايد مرة أخرى .

ومن الجانب الآخر فان ازدياد درجة حرارة المائع يؤدى الى تناقص أقصى معدل للتصرف والعلو الكلى للمضخة .