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Heat Storing Capacity of Boiler*

(Received October 10, 1953)

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Abstract

It was obtained the general energy equation for evaporating system such as a boiler. Using this equation, the heat storing capacity of boiler from the data of the steam table of the Japan Society of Mechanical Engineers was calcurated, and it was compared this results to that of Schroeders.

I. Introduction

In the evaporation system, such as a boiler, it is filled with partly saturated liquid and partly saturated vapour. If the vapour is taken out of the vessel, the pressure decreases and new vapour is generated by its own thermal capacity. The quantity of vapour generated in this case in [kg] when the pressure decreases by 1 kg/cm^2 is called " heat storing capacity" of the evaporating system.

To know the values of storing capacity is very important problem in the automatic controles of boiler. Formerly its values is obtained only approximately,[1][2][3] so I have tried to find it by exact calcuration.

II. General Energy Equation for Boiler

In Fig. 1, A is the vessel in which the saturated liquid and vapour coexist, for instance it is the boiler proper in the case of boiler. We consider that a certain rate of feed water and heat was supplied to the vessel, and another rate of steam was taken out of it. To get the general energy equation of the system, we will take the notations as follows :

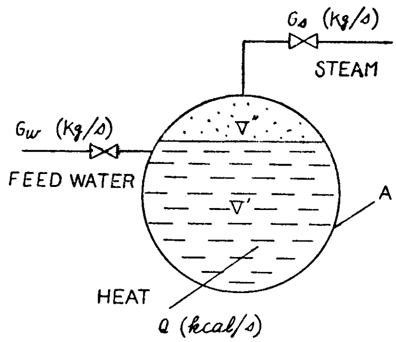

Fig. 1

* Read before the 3rd Meeting of Applied Mechanics, Sep. 9, 1953.

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(1) Zinsen : Dampfkessel und Feuerungen, Springer, 1949.

(2) Ledinegg : Dampferzeugung, Dampfkessel, Feuerungen, Springer, 1952.

(3) Schroeder : Grundsaetzliche zur Kesselregelung an Hochdruckkesseln, Siemens Zeitschrift, 1951 – 4.

V' = volume of water space in [m^3],
V'' = ditto of steam space in [m^3],
V_o = total volume in the vessel in [m^3],
G = sum of weight of water and steam in the vessel in [kg],
Q = rate of heat supply to the vessel in [kcal/s],
G_w = rate of supply of feed water in [kg/s],
G_s = rate of taking out of steam in [kg/s],
E = sum of energy stored in the vessel in [kcal],
E_t = heat capacity of the vessel wall in [kcal],
G_t = weight of the vessel wall in [kg],
c_t = specific heat of the vessel wall in [kcal/kg °C],
t_t = temperature of the vessel wall in [°C],
φ = ratio of contribution of the heat capacity of the vessel wall to the sum of energy of the water and steam in the vessel,
r = latent heat of vaporization in [kcal/kg],
v' = specific volume of saturated water in [m^3/kg],
v'' = ditto of dry saturated steam in [m^3/kg],
u' = internal energy of the saturated water in [kcal/kg],
u'' = ditto of dry saturated steam in [kcal/kg],
i'' = enthalpy of dry saturated steam in [kcal/kg],
i_w = ditto of feed water in [kcal/kg],
P = pressure in the vessel in [kg/m^2],
p = ditto in [kg/cm^2],
z = time in [s],
A = thermal equivalent of work = 1/427 [kcal/kg m].

We may assume the magnitude of V_O, G_t, c_t is constant, but other quantities are variable with the time. The height of the vessel, in the case of modern water tube boiler, may be about 30 m or more, therefore the pressure and the temperature of the water in the vessel may be vary with the position, but we assume these are constant throughout the vessel. Also we assume the flowed out steam is dry saturated, though it may be somewhat wet.

Then the sum of weight of water and steam in the vessel is

$$G = \frac{V'}{v'} + \frac{V''}{v''} \qquad \text{(1)}$$

The sum of energy stored in the vessel is

$$E = \frac{u'}{v'} V' + \frac{u''}{v''} V'' \qquad \text{(2)}$$

The total volume in the vessel is

$$V_O = V' + V'' \qquad \text{(3)}$$

The rate of increase of the total weight in the vessel is equal to the difference of the weight of supplied water and that of flowed out steam per unit time. Or we have

$$\frac{dG}{dz} = G_{w} - G_{s} \qquad \cdots\cdots (4)$$

The rate of increase of the sum of energy in the vessel and the contributed heat capacity of the vessel wall is equal to the difference of supplied energy and taken out energy per unit time, therefore we have.

$$\frac{d(E+\varphi E_t)}{dz} = Q + G_w\, i_w - G_s i'' \qquad \cdots\cdots (5)$$

The heat capacity of the vessel wall is

$$E_t = G_t\, c_t\, t_t \qquad \cdots\cdots (6)$$

Eliminating V', V'', E and G_s from eq. (1)~(5), we have

$$\frac{dG}{dz} = \frac{G}{X}\frac{d(i''-X)}{dz} + \frac{V_0}{X}\frac{d}{dz}\left(\frac{u''-u'}{v''-v'}\right) + \frac{1}{X}\frac{d(G_t\, c_t\, t_t)}{dz} + \frac{G_w(i''-i_w)-Q}{X} \qquad \cdots\cdots (7)$$

where

$$X = APv'' + \frac{v''(u''-u')}{v''-v'} = \frac{rv''}{v''-v'} \qquad \cdots\cdots (8)$$

If we put

$$g = G/V_0, \qquad \cdots\cdots (9)$$

g is the sum of weight of saturated water and steam per unit volume (in kg/m^3) in the vessel. Using eq. (9), eq. (7) may be written as follows:

$$\frac{dg}{dp} = \frac{g}{X}\frac{d(i''-X)}{dp} + \frac{1}{X}\frac{d}{dp}\left(\frac{u''-u'}{v''-v'}\right) + \frac{1}{XV_0}\frac{d(G_t c_t t_t)}{dz}\frac{dz}{dp} + \frac{G_w(i''-i_w)-Q}{XV_0}\frac{dz}{dp} \qquad \cdots\cdots (10)$$

The eq. (7) or (10) is the most general equation for the boiler or evaproating system in general.

III. Heat Storing Capcity of Boiler

In the ideal case of no heat capacity of the vessel wall and equilibrium state of inflow and outflow energy of the vessel, we can neglect the 3rd and 4th terms in the right side of eq. (10). Namely

$$\frac{dg}{dp} = \frac{1}{X}\frac{d(i''-X)}{dp}g + \frac{1}{X}\frac{d}{dp}\left(\frac{u''-u'}{v''-v'}\right) \qquad \cdots\cdots (11)$$

The coefficient of g in the 1st term and the 2nd term are the function of the pressure only, therefore this equation is normal linear differential equation of the first order. The left side of this equation gives heat storing capacity of the boiler. But the values of the reciprocal of it is more useful for practical case, so I have

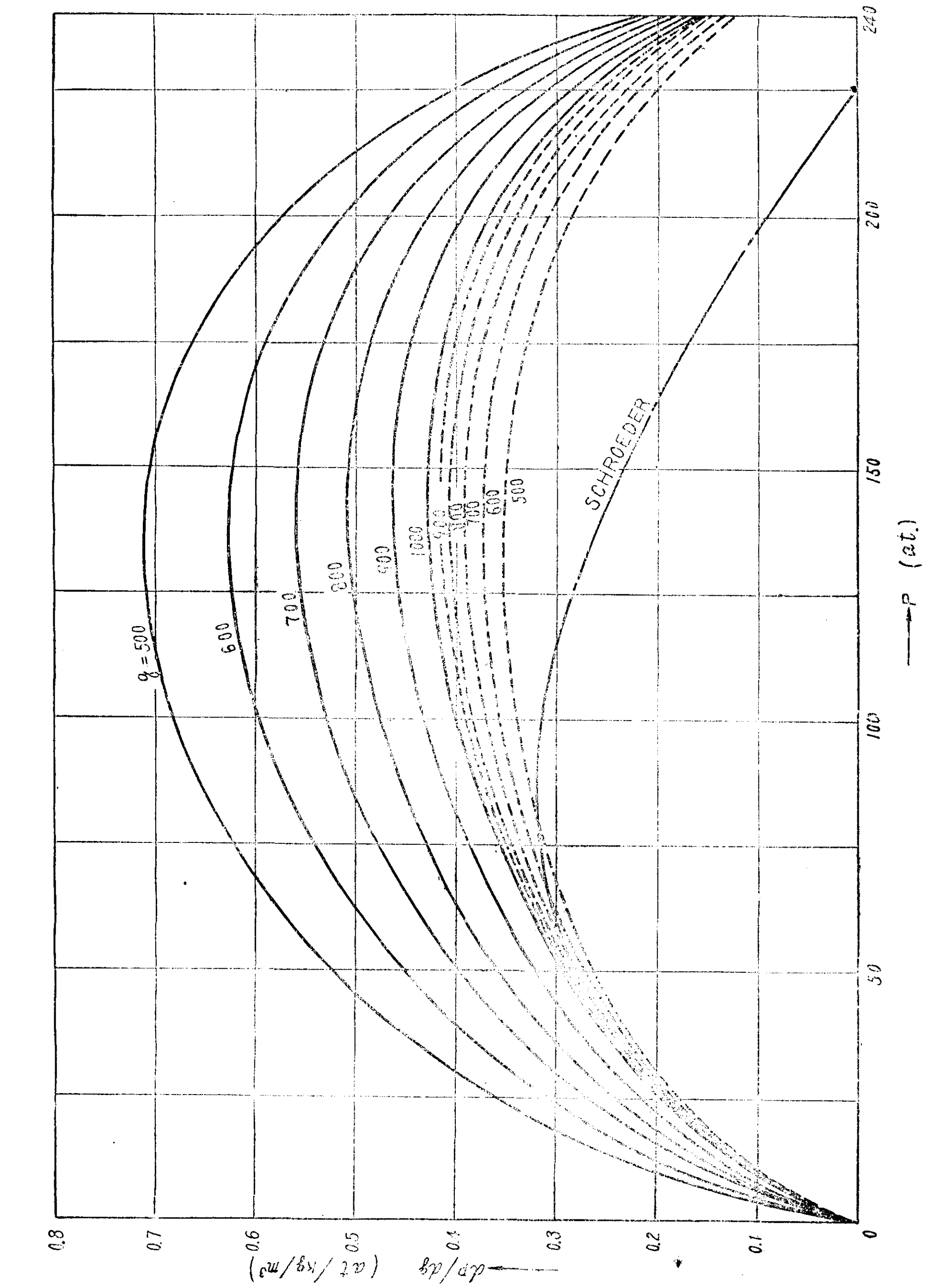

Fig. 2

calcurated the values of dp/dg from eq. (11) using the new steam table of the Japan Society of Mechanical Engineers. This results is shown in Table 1 and Fig. 2. The full line curves in Fig. 2 show the value of dp/dg, or the pressure

Table 1. Values of dp/dg

p	$\frac{1}{X}\frac{d(i''-X)}{dp}$	$\frac{1}{X}\frac{d}{dp}\left(\frac{u''-u'}{v''-v'}\right)$	dp/dg $at/kg/m^3$					
at	$1/at$	$kg/m^3/at$	g=1000	900	800	700	600	500
5	7.45	211.5	0.0659	0.0730	0.0819	0.0931	0.108	0.128
10	4.35	191.8	0.106	0.118	0.132	0.149	0.173	0.204
20	2.51	174.6	0.170	0.188	0.209	0.237	0.272	0.320
30	1.83	164.7	0.219	0.241	0.268	0.302	0.346	0.405
40	1.46	158.1	0.260	0.286	0.317	0.357	0.407	0.474
60	1.07	150.3	0.321	0.352	0.390	0.436	0.495	0.573
80	0.855	145.7	0.367	0.401	0.443	0.494	0.557	0.641
100	0.723	143.2	0.398	0.434	0.477	0.531	0.597	0.682
120	0.625	142.2	0.419	0.457	0.501	0.555	0.622	0.708
140	0.558	142.8	0.427	0.464	0.508	0.562	0.627	0.710
160	0.504	146.0	0.425	0.460	0.503	0.553	0.616	0.694
180	0.462	154.1	0.406	0.439	0.478	0.525	0.581	0.651
200	0.425	170.7	0.370	0.399	0.432	0.471	0.518	0.576
215	0.400	194.4	0.324	0.348	0.375	0.407	0.444	0.489

depression in [*at*] when 1 kg of steam was newly generated by self evaporation for g = 1000, 900, 800, 700, 600 and 500 kg/m³, respectively. While, the dotted line curves show the pressure depression in [*at*] when the water vaporizes by 1/1000 of its original quantity, or g/1000 kg. The chain line curve indicates, for comparison, the values of dp/dg given by Schroeder.[1] At the higher pressure range, above about 40 at, the difference of the calcurated values in this case to those of Schroeders is very large. I think this cause is due to the fact that some of the basic equations of Schroeders, corresponding to eqs. (1)~(5), are only approximate one.

1) *cf.* the foot note (3) on p. 1