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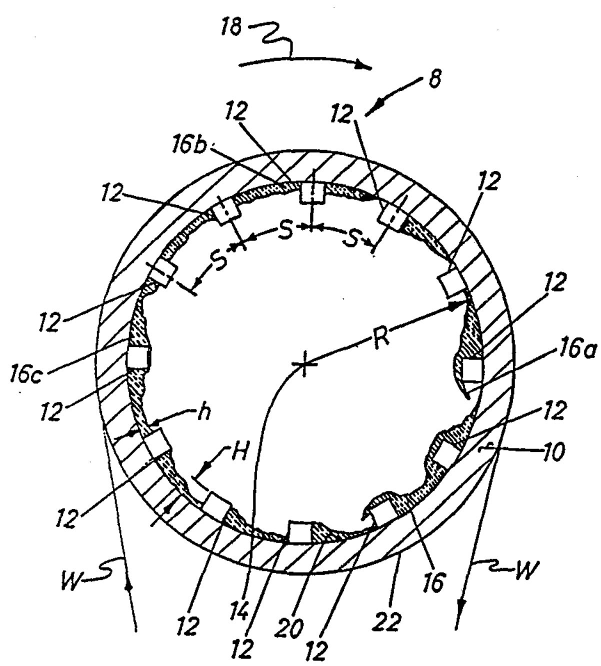
(54) Rotary drying drum.

(57) A cylindrical, rotary drying drum (10), which is adapted to rotate about its horizontally disposed longitudinal axis (14) is equipped with a plurality of spoiler bars (12) mounted to its inner peripheral surface (20). The spoiler bars (12) extend coaxially with the axis of rotation and are circumferentially spaced from one another according to the expression $S = \pi\sqrt{Rh}\,(1.50 \pm 0.25)$ and have a height H in cm determined by the expression $H = \frac{(5,91)}{N}(1.0 \pm 0.25)$ where R is the radius of the drum's inner surface, h is the condensate (16) thickness, and N is the number of spoiler bars mounted within the dryer drum.



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ROTARY DRYING DRUM.

This invention relates to the field of drying a moist traveling web which is carried on the surface of a rotary dryer drum that is heated by introducing a condensable vapor into its sealed interior. More particularly, this invention relates to a rotary, steam heated dryer drum equipped with spoiler bars mounted against its inner peripheral surface to interrupt the condensate layer formed as the steam condenses. Still more particularly, this invention concerns the relationship between the number and height of the spoiler bars in conjunction with the depth of the condensate layer, to enhance the condensate coefficient of heat transfer.

Prior work in this field is succinctly summarized in U.S. Patent No. 3,724,094 by D.W. Appel and S.H. Hong. This prior art teaches the enhancement of the heat transfer coefficient in a steam heated dryer drum equipped with spoiler bars attached to the inner peripheral surface when the spoiler bars are spaced from each other by a circumferential distance in the range of 2,4 $\sqrt{d}$ to 7,4 $\sqrt{d}$ cm where "d" is the internal diameter of the drum in cm. Another expression for the spacing of the spoiler bars within such a steam heated cylindrical drying drum is given by the expression $a = (1 \pm 0.25) \pi \sqrt{Rh}$ where "a" is the spacing between adjacent bars, "R" is the inside radius of the drum and "h" is the average condensate depth within the drum.

In this prior art, the condensate depth in dryer rolls was measured and then minimum, average and maximum values determined for acceptable condensate depth. With these condensate depth values, theoretical studies were conducted to determine the resonant frequency of condensate sloshing between two adjacent, axially extending bars mounted to the inner peripheral surface of a cylindrical dryer drum. Then, using the radius of the inner surface of the dryer drum cylinder, the frequency of rotation of the dryer shell was equated to the frequency of condensate sloshing to develop an expression for the spacing of the spoiler bars in terms of the dryer drum inner radius and condensate thickness.

The spacing of spoiler bars around the inner periphery of steam heated dryer cylinders according to this prior art works well, but it requires the application of a fairly large number of spoiler bars. For example, on a standard 1,52 m outside diameter dryer drum commonly used on papermaking machinery, the number of spoiler bars based on the prior art teaching would range from about 24 to about 72. Since each of these bars must be manufactured to strict specifications and installed with a great deal of care and precision, the adaptation of dryer drums with spoiler bars to enhance drying of a web can be both time consuming and expensive.

There are only three basic ways of increasing the heat transfer through a steam heated wall of a cylindrical dryer (i.e. 1) decreasing the condensate depth by bringing the syphon closer to the inner wall; 2) bypassing the condensate by providing ribs along the dryer drums inner surface; and 3) generating rurbulence in the condensate layer). Bringing the syphon closer to the rotating wall creates and aggravates operational problems, and machining ribs in the internal surface is very expensive, so it is believed that improving the heat transfer by the creation of turbulence with spoiler bars represents the most promising direction.

However, insofar as the spoiler bar height and the spacing of the bars within the periphery of the dryer cylinder, the prior art teaching was quite specific and narrow. Specifically, with a spoiler bar height stipulated as preferably being about 2 - 3 times the average condensate depth, and the optimum spoiler bar peripheral spacing being about 14,5 cm, it was expressed that spoiler bar spacing significantly smaller and larger than this 14,5 cm spacing would produce reduced heat transfer through the cylindrical wall of the dryer drum.

This invention represents an improvement over the prior teachings about the enhancement of heat transfer through a steam heated rotating cylindrical dryer drum utilizing spoiler bars, and the relationship between the condensate depth, spoiler bar height and the spacing of the spoiler bars within the dryer roll. It was found that increasing the spoiler bar height and the spacing of the bars along the inner surface of the dryer drum in conjunction with a decreased condensate depth, produces greater turbulence in the condensate and thus an increased rate of heat transfer through the dryer wall than would have been expected from prior teachings.

This permits the condensate to be collected by the syphon without requiring a precision relationship between the bottom of the syphon and the interior wall of the rotating dryer roll. It also greatly reduces the number of spoiler bars required in a dryer to achieve the desired rate of heat transfer. For example, in an ordinary 1,52 m outside diameter dryer roll having a 1,467 cm interior diameter, it has been determined that the number of spoiler bars would range from about 8 to about 20, where as the prior art would teach the optimum number of spoiler bars should be about 30. The improvement in heat transfer which results from decreasing the number of spoiler bars from that specified by the prior art is not only unexpected, but very dramatic.

In this invention, the spoiler bar height in cm is determined from the expression $H = \frac{(5.91)}{N}(1.0 \pm 0.25)$, (equation (1)), and the spacing between the spoiler bars is determined from the expression $S = \pi\sqrt{Rh}\,(1.50 \pm 0.25)$, (equation (2)), where the number of bars, assuming negligible bar width, is related to the inner radius of the cylindrical dryer roll and the spacing between bars by the geometrical relationship $N = \frac{2\pi R}{S}$ (equation (3)), where S is the spacing, R is the inner radius of the cylindrical dryer roll, h is the depth of the condensate, and H is the spoiler bar height.

Accordingly, it is an object of this invention to provide a rotatable, condensable vapor heated dryer drum equipped with internally mounted, peripherally spaced, axially extending spoiler bars wherein the height and spacing of the spoiler bars and depth of the condensate of the vapor are determined by the aforementioned mathematical expressions.

Another object of the invention is to enhance the coefficient of heat transfer in a steam heated dryer drum utilizing spoiler bars mounted on the inner peripheral surface thereof.

Still another object of the invention is to provide a steam heated dryer drum designed to have enhanced heat transfer for a condensate depth of about 0,32 - 2,54 cm and equipped with about 8 - 20 spoiler bars.

These and other objects, features and advantages of the invention will become apparent to those skilled in the art when the description of the preferred embodiment is read in conjunction with the attached drawings.

Figure 1 is a cross sectional end view of a cylindrical dryer drum showing a plurality of peripherally spaced, axially extending spoiler bars attached to its inner wall. The spoiler bars are shown with exaggerated width for purpose of illustration, but their actual width is negligible compared to the spacing between bars.

Figure 2 is a graph representing the relationship between the spoiler bar spacing S and the condensate thickness h, with the number of spoiler bars N also indicated, in a dryer roll of 152 cm external diameter and 146,7 cm internal diameter, both for the Appel et al. U.S. Patent 3,724,094 and for the present invention.

Figure 3 is a graphical representation of the heat transfer coefficient h_L as a function of the condensate thickness h for 10 equally spaced spoiler bars of different heights H in a cast-iron dryer drum of 152 cm external diameter and 146,7 cm internal diameter, with a dryer speed of 20 m/sec.

Figure 4 is a graphical representation of the heat transfer coefficient h_L as a function of condensate thickness h for 15 equally spaced spoiler bars with different spoiler bar heights H in a cast-iron dryer drum of 152 cm external diameter and 146,7 cm internal diameter, with a dryer speed of 20 m/sec.

Figure 5 is a graphical representation of the heat transfer coefficient h_L as a function of the condensate thickness h for 15 equally spaced spoiler bars having a height H = 0,95 cm in a cast-iron dryer drum of 152 cm external diameter and 146,7 cm internal diameter, with a dryer speed of 20 m/sec.

In a papermaking machine, the moist paper web is partially or completely dried by passing it onto the surface of one or more rotating dryer rolls having cylindrical, cast iron drum. A condensable vapor, such as steam, is introduced into the interior of the drum and condenses on its inner peripheral surface. As the steam condenses, it gives up heat which is passed through the drum wall to dry the paper held against its outer surface for a portion of its circumference. The higher the heat transfer coefficient through the drum wall, the more efficient this process is. This is important not only from an energy standpoint, but it is a factor in how fast the machines can run and still dry the web to the desired dryness. It also is a factor in the number of dryer rolls needed to produce dry paper at a desired speed.

However, as the steam condenses, the condensate layer formed on the inner peripheral surface of the drum effectively functions as an insulation layer impeding the transfer of heat from the steam to the inner surface of the dryer drum. As the paper machine speeds approach 5 - 6 m/s, the condensate begins to rim around the inner peripheral surface of the dryer drum instead of collecting in a puddle at the bottom of the drum as it rotates about its horizontally disposed longitudinal axis.

This is shown in Figure 1 which illustrates an end view of a cross section of a dryer roll 8 having a drum 10 with an inner cylindrical surface 20 and an outer cylindrical surface 22 over which a moist web W is disposed to receive heat to drive out the moisture and dry the web.

The radial distance from the horizontally disposed, longitudinal axis of rotation 14 to the periphery of the internal surface 20 is R and a plurality of spoiler bars 12 are mounted to the internal surface 20 by suitable means, such as screws. These spoiler bars extend axially within the dryer roll and are spaced apart circumferentially an equal distance S. The spoiler bars have a height H which interacts with the condensate 16 as the dryer rotates in the direction of arrow 18 to cause turbulence in the condensate as it is forced to travel up and over the top of the oncoming spoiler bars as they travel from the twelve o'clock position downwardly to the three o'clock and six o'clock positions where the condensate tends to accumulate. The average condensate thickness h, for purposes of illustration, is shown at a point between two successive spoiler bars at about the eight o'clock position. The shape of the condensate changes at different positions around the inner circumference of the dryer drum as it comes under the combined effects of the forces of rotation and gravity. At the five o'clock, the condensate is more or less of a normal thickness 16 as it spills over the spoiler bars. At about the three o'clock position, greater turbulence 16a is shown as the condensate spills over the bars. Near the twelve o'clock position, the condensate 16b flattens out, and at about the nine o'clock position, the condensate again begins to build up as it sloshes against the oncoming spoiler bars.

In the Appel et al U.S. Patent No. 3,724,094, two of the four parameters affecting the heat transfer coefficient of a dryer drum equipped with spoiler bars were identified as the bar height and the condensate thickness. In the preferred embodiment of this patent, these two parameters were expressed in terms of each other. Specifically, preferred condensate depth ranged from about 1 mm to about 3 mm while the preferred spoiler bar height ranged from about 2 - 3 times the average condensate depth, or about 2 - 9 mm in height. Additionally, the spacing between adjacent bars was related to the condensate depth and the dryer inside radius by the expression $S = \pi \sqrt{Rh}\ (1.0 \pm 0.25)$, with the preferred spacing being about 14,6 cm.

In this invention, the same four parameters, namely bar height, bar spacing, condensate depth, and the inner radius, are also interrelated, but according to relationships which provide for fewer bars and higher heat transfer rates than taught by the prior art. Specifically, the relationships between these four parameters are given by the preceding equations (1), (2), and (3).

Thus, in this invention, the spoiler bar height becomes an inverse function of the number of bars. The fewer bars, the greater their height. An important aspect of this relationship is that higher bars tend to produce increased turbulence in the condensate as it spills over the bars and sloshes against adjacent bars. This means that greater turbulence and correspondingly higher heat transfer rates can be produced with fewer bars.

Since the spoiler bar spacing S in this invention is given by the expression $S = \pi \sqrt{Rh}\ (1.5 \pm 0.25)$, the spoiler bar spacing is a square root function of the product of the radius of the dryer inner surface and the condensate depth. This square root relationship is similar to that taught by the prior art. However, the proportionality constant 1.5 is 50% larger than the 1.0 proportionality constant taught by the prior art. This invention therefore specifies 33% fewer spoiler bars for a given condensate depth, which results in an unexpected and dramatic improvement in the condensate heat transfer coefficient, as is shown in the data herein presented. The term 0.25 in the above equation is used to provide an acceptable range for the spoiler bar spacing considering the imprecise nature of the condensate sloshing over the spoiler bars during rotation of the dryer roll. For computation purposes, the width of the spoiler bars themselves is considered to be nigligible so the spacing S actually represents the distance between adjacent spoiler bars along the inner wall of the dryer roll.

In Figure 2, the spoiler bar spacing S about the inner circumference of a dryer drum, (white area), were plotted against the condensate thickness h according to the expressions in claims 1 and 7 of the Appel et al U.S. Patent 3,724,094. The vertical width of the graphical representation of the spoiler bar spacing for a given condensate thickness is determined by the $\pm$ 0.25 tolerance factor which is used in the calculations because of the inexact nature of condensate sloshing within a rotating dryer drum. The shaded area above the "white" area represents the spoiler bar spacing for various condensate thicknesses according to this invention. This will be explained in more detail below.

Figure 3 - 5 show curves wherein the condensate heat transfer coefficient in kcal/hm^2 $^{\circ}$C is plotted as a function of the condensate thickness in cm in a standard 152 cm cast-iron dryer drum having an internal diameter of 146,7 cm. Figure 3 represents data taken for a dryer drum equipped with 10 equally spaced spoiler bars mounted to the interior surface 20 of the dryer drum while Figures 4 and 5 represent data taken on the same dryer drum equipped with 15 and 30 spoiler bars, respectively.

The spacing S between a plurality N of spoiler bars equally spaced about the circumference C of the inner surface 20 of the dryer roll 8 is given by the geometrical relationship

$$S = C/N \qquad (4)$$

Substituting $2\pi R = C$ (R is the inner radius of the dryer drum) results in the following expression

$$S = \frac{2\pi R}{N} \qquad (5)$$

or

$$N = \frac{2\pi R}{S} \qquad (6)$$

According to the invention, the optimum spacing S between spoiler bars is

$$S = \pi \sqrt{Rh}\ (1.50 \pm 0.25) \qquad (2)$$

From the curves in Figures 3 - 5 and the knowledge gained from the experience of conducting the various tests, it was determined that the range for the preferred number of spoiler bars was from about 8 to about 20. For fewer than about 8 spoiler bars, the condensate remains too thick between the bars during rotation of the dryer roll and this causes an excessive increase in the power required to maintain the dryer rotation. For more than about 20 spoiler bars, the optimum depth of condensate for maximum transfer of heat is too small and may not be achievable with conventional syphoning equipment. This is illustrated by the following example:

1) For 20 bars in a 152 cm dryer roll (int.diam.= 146,7 cm)

$$S = \frac{2\pi R}{N} = \frac{2\pi(73.34)}{20} = 23.04\ \text{cm}$$

$$h = \left(\frac{S}{1.5\pi}\right)^2 \frac{1}{R} = \left(\frac{23.04}{1.5\pi}\right)^2 \frac{1}{73.34} = 0.32\ \text{cm}$$

2) For 8 bars in a 183 cm dryer roll (int.diam.= 177 cm)

$$S = \frac{2\pi R}{N} = \frac{2\pi(88,27)}{8} = 69,32\ \text{cm}$$

$$h = \left(\frac{S}{1.5\pi}\right)^2 \frac{1}{R} = \left(\frac{69.32}{1.5\pi}\right)^2 \frac{1}{88.27} = 2,45\ \text{cm}$$

An expression for the height H of the spoiler bars was derived based on experiences gained from the tests. This expression is

$$H = (5{,}91/N)\ (1.0 \pm 0.25)\ \text{cm} \qquad (1)$$

Since the preferred number of spoiler bars is known, the preferred height range for the preferred range for the number of spoiler bars is

$$1{,}52 \leq H \leq 3{,}81\ \text{cm}$$

Referring again to figure 2, equation (5) is used to compute the values for spoiler bar spacing for various condensate thicknesses. This range is the shaded area shown. Again, the ± 0.25 tolerance factor produces a vertical width for the range of desired spacing. The upper and lower spacing limits were determined from equation (3) using the range of the preferred number of bars. Thus

$$S = \frac{2\pi R}{N}$$

$$S_{max} = \frac{2\pi(73,34)}{8} = 57,6 \text{ cm}$$

$$S_{min} = \frac{2\pi(73,60)}{20} = 23,1 \text{ cm}$$

An evaluation of research tests indicated that dryers equipped with 10 - 15 bars were capable of achieving higher heat transfer coefficients than dryers equipped with 25 - 30 bars. It was determined that this was because of a different relationship between all of the three major parameters of spoiler bar spacing, height and condensate thickness, affecting heat transfer in a spoiler bar equipped dryer. In other words, it is believed that rather than optimizing one of the major parameters, say, for example, making the condensate depth as thin as possible, it was concluded that the problem could best be approached by enhancing the condensate turbulence in conjunction with the reduction of the condensate thickness.

Since increased turbulence ideally permits both an increase in the amount of steam intrained by the condensate (and consequent lessening of its insulating property), and an increase in the incidence where such high degree of turbulence exposes more of the dryer wall directly to live steam, this invention permits a high heat transfer coefficient even when the condensate thickness is relatively large (i.e. about 0,64 - 1,27 cm). Even more significantly, this is accomplished with relatively few (i.e. about 8 - 20) spoiler bars.

Therefore, this invention resides in the combination of relatively few spoiler bars, each having a relatively large height used in conjunction with a relatively thick layer of condensate, but thinner than taught by the prior art. This combination has the additional advantage of allowing a greater siphon clearance for condensate removal which lessens the likelihood of operational problems associated with relative movement between the siphon and the inner drum wall at high speeds, which can be greater than a mile a minute on modern papermaking machines.

The difference between this invention and the prior art can perhaps best be illustrated by referring to figures 3 - 5 in conjunction with examples utilizing the expressions for condensate thickness for a given number of spoiler bars.

Condensate Thickness h For 15 Rows Of Equally Spaced Spoiler Bars In A Dryer Drum Having A 146,7 cm Internal Diameter.

Neglecting the 0.25 tolerance factor in equation (2) to simplify the comparison, we have:

This Invention

$$S = (1.5)\pi\sqrt{Rh} \qquad (2)$$

or

$$h = \frac{1}{R}\left(\frac{S}{1.5\pi}\right)^2$$

for R = 73,34 cm, the bar spacing can also be expressed by:

$$S = \frac{2\pi R}{N} = \frac{2\pi(73,34)}{15}$$

S = 30,7 cm bar spacing

$$h = \frac{1}{73,34}\left(\frac{30.7}{1.5\pi}\right)^2$$

h = 0,58 cm

Appel et al U.S.Patent 3,724,094

$$S = \pi\sqrt{Rh} \qquad (9)$$

or

$$h = \frac{1}{R}\left(\frac{S}{\pi}\right)^2$$

for R = 73,34 cm, the bar spacing can also be expressed by:

$$S = \frac{2\pi R}{N} = \frac{2\pi(73,34)}{15}$$

S = 30,7 cm bar spacing

$$h = \frac{1}{73,34}\left(\frac{30.7}{\pi}\right)^2$$

h = 1,30 cm

The above example shows that for the same geometrical configuration, specifically a 73,34 cm dryer inner radius and 15 rows of spoiler bars, this invention teaches that the optimum condensate depth is 0,58 cm while the prior art teaches that the optimum condensate depth is substantially thicker, 1,30 cm.

Figures 3 - 5 show the condensate heat transfer coefficient h_L for spoiler bars of various heights and different condensate thicknesses. Since the condensate thickness for the Appel et al dryer equipped with spoiler bars can be calculated from their equation (9) above and the same can be determined for this invention from equation (2) in the example above, the condensate thicknesses corresponding to a given number of spoiler bars can be compared. This has been done for 10, 15 and 30 spoiler bars in Table 1 below:

TABLE 1

Cast-Iron Dryer
152 cm ext. diam.
146,7 cm int. diam.
20 m/s Dryer Speed

No. Spoiler Bars	Optimum Condensate Thickness (cm)		Condensate Heat Transfer Coefficient h_L: kcal/hm^2 °C	
	Prior Art	Invention	Prior Art	Invention
30	0,33	0,15	1737	2653
15	1,30	0,58	1809	2315
10	2,95	1,30	338	3063

Referring to Figure 3, it is seen that a combination of a condensate thickness h of about 1,27 cm and a spoiler bar height H of 3,81 cm on a standard dryer drum equipped with 10 spoiler bars, the heat transfer coefficient is about 3063 kcal/hm^2 °C, whereas the prior art would have specified a condensate thickness of over 2,54 cm, which, for a preferred spoiler bar height of about 0,95 cm provides a heat transfer coefficient of about 338 kcal/hm^2 ^{o}C.

Similarly, in Figure 4, the heat transfer coefficient on a drum equipped with 15 spoiler bars according to this invention is about 2315 kcal/hm^2 ^{o}C at a condensate depth of about 0,58 cm for a spoiler bar height of 2,54 cm (shown as a dashed line). The corresponding heat transfer coefficient for the same dryer roll at a condensate thickness of 1,30 cm for 0,95 cm high spoiler bars is about 1809 kcal/hm^2 ^{o}C.

In Figure 5, in the dryer roll equipped with 30 spoiler bars, the optimum condensate thickness according to this invention is about 0,15 cm at which the head transfer coefficient is about 2653 kcal/hm^2 ^{o}C. At the condensate thickness determined according to the prior art, about 0,33 cm, the heat transfer coefficient is about 1737 kcal/hm^2 ^{o}C.

Thus, an improved spoiler bar equipped dryer arrangement is disclosed which achieves improved heat transfer through a new combination of spoiler bar spacing and height, and the depth of condensate.

CLAIMS:

1. In a hollow cylindrical dryer drum (10) rotatable about its longitudinal axis (14) and equipped with a plurality of spoiler bars (12) mounted to its inner peripheral surface (20)and extending longitudinally, substantially parallel with the axis of rotation, said drum adapted to receive a heated condensable vapor, such as steam, within its interior to heat the cylindrical drum wall, and syphon means within the dryer drum to gather and remove the condensate (16), the improvement characterized in having:

the number of spoiler bars (12) mounted within the drum (10) ranging from about 8 to about 20;

means for maintaining the condensate (16) at a depth of between about 0,32 cm to about 2,54 cm;

the spoiler bars (12) spaced circumferentially about the drum wall (20) according to the expression $S = \pi\sqrt{Rh}(1.50 \pm 0.25)$, where R is the radius from the axis of rotation to the inner drum wall, h is the average condensate thickness and S is the spacing between adjacent bars;

whereby turbulence in the condensate and heat transfer through the dryer drum wall are enhanced.

2. The combination as set forth in claim 1, characterized in that

the spoiler bar (12) height is given by the expression $H = \frac{5,91}{N}(1.0 \pm 0.25)$ where H is the height in cm and N is the number of spoiler bars (12).

3. The combination as set forth in claim 1, characterized in that

the preferred height of the spoiler bars (12) ranges from about 1,5 cm to about 3,8 cm.

4. The combination as set forth in claim 2 characterized in that

the condensate (16) depth is given by the expression

$$h = \frac{1}{R}\left(\frac{S}{(1.5 \pm 0.25)\pi}\right)^2$$

5. In a hollow cylindrical drum (10) rotatable about its longitudinal axis, and equipped with a plurality of spoiler bars (12) mounted to its inner peripheral surface (20) and extending longitudinally, substantially parallel with the axis of rotation, said drum adapted to receive a heated condensable vapor, such as steam, within its interior to heat the cylindrical drum wall, and syphon means within the dryer drum to gather and remove the condensate (16), the method characterized in:

arranging the syphon means to maintain the condensate thickness within the drum (10) to less than about 1,54 cm;

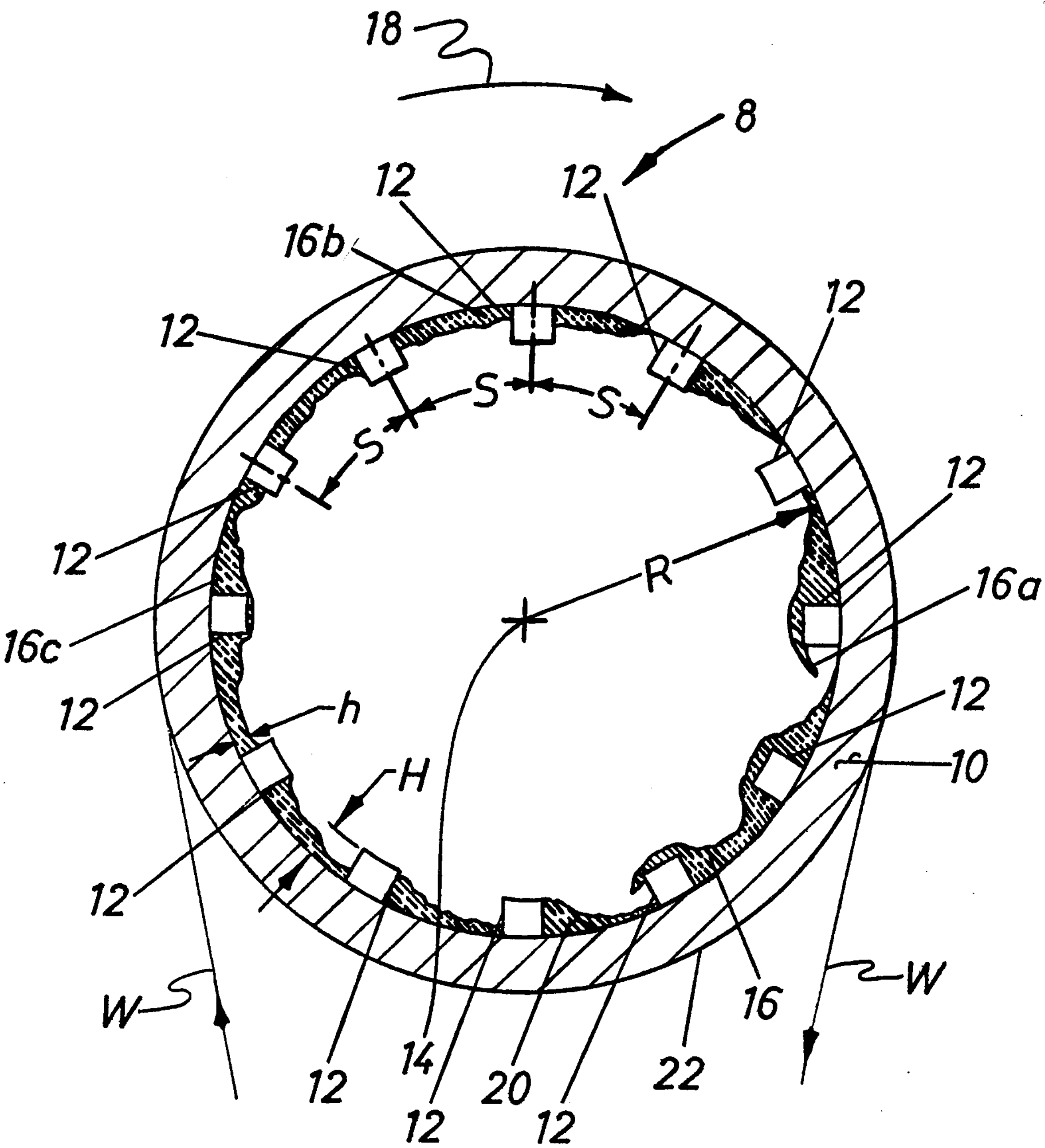
spacing the spoiler bars (12) circumferentially about the drum wall (20) such that the distance between adjacent spoiler bars ranges from about 20 cm to about 56 cm;

extending the height of the spoiler bars from the drum wall according to the expression $H = \frac{5,91}{N} (1.0 \pm 0.25)$ where H is the spoiler bar height in cm and N is the number of spoiler bars;

whereby turbulence in the condensate and heat transfer through the dryer drum wall are enhanced.

6. The method as set forth in claim 5, characterized in that

the syphon means is arranged to maintain the condensate depth between about 0,64 cm to about 1,27 cm.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12
16b
12
12
S
S
S
12
R
16a
16c
12
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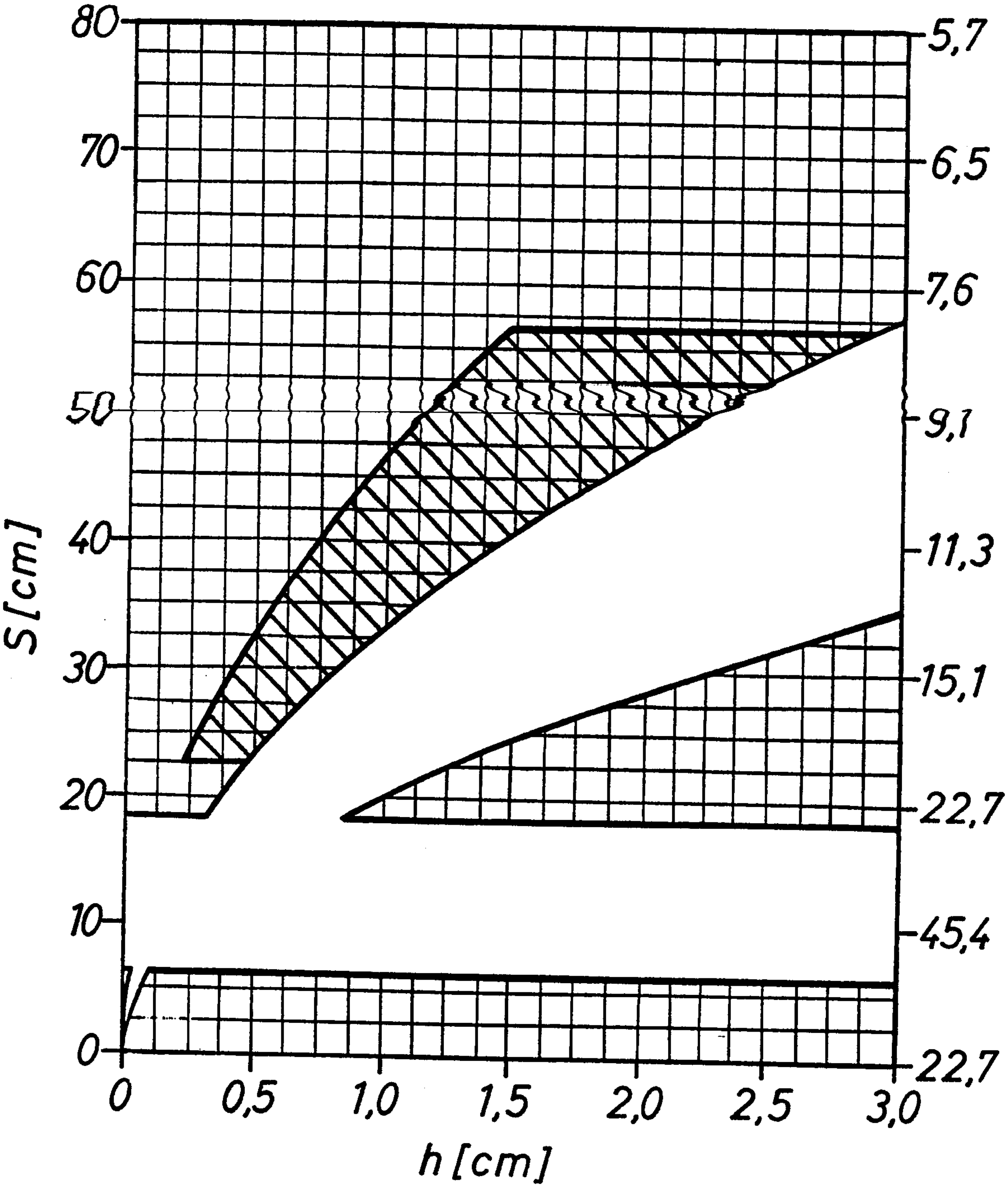
h
12
H
10
12
W
W
16
12
14
20
22
12
12

FIGURE 1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70
60
50
40
30
20
10
0
S [cm]
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6,5
7,6
9,1
11,3
15,1
22,7
45,4
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1,0
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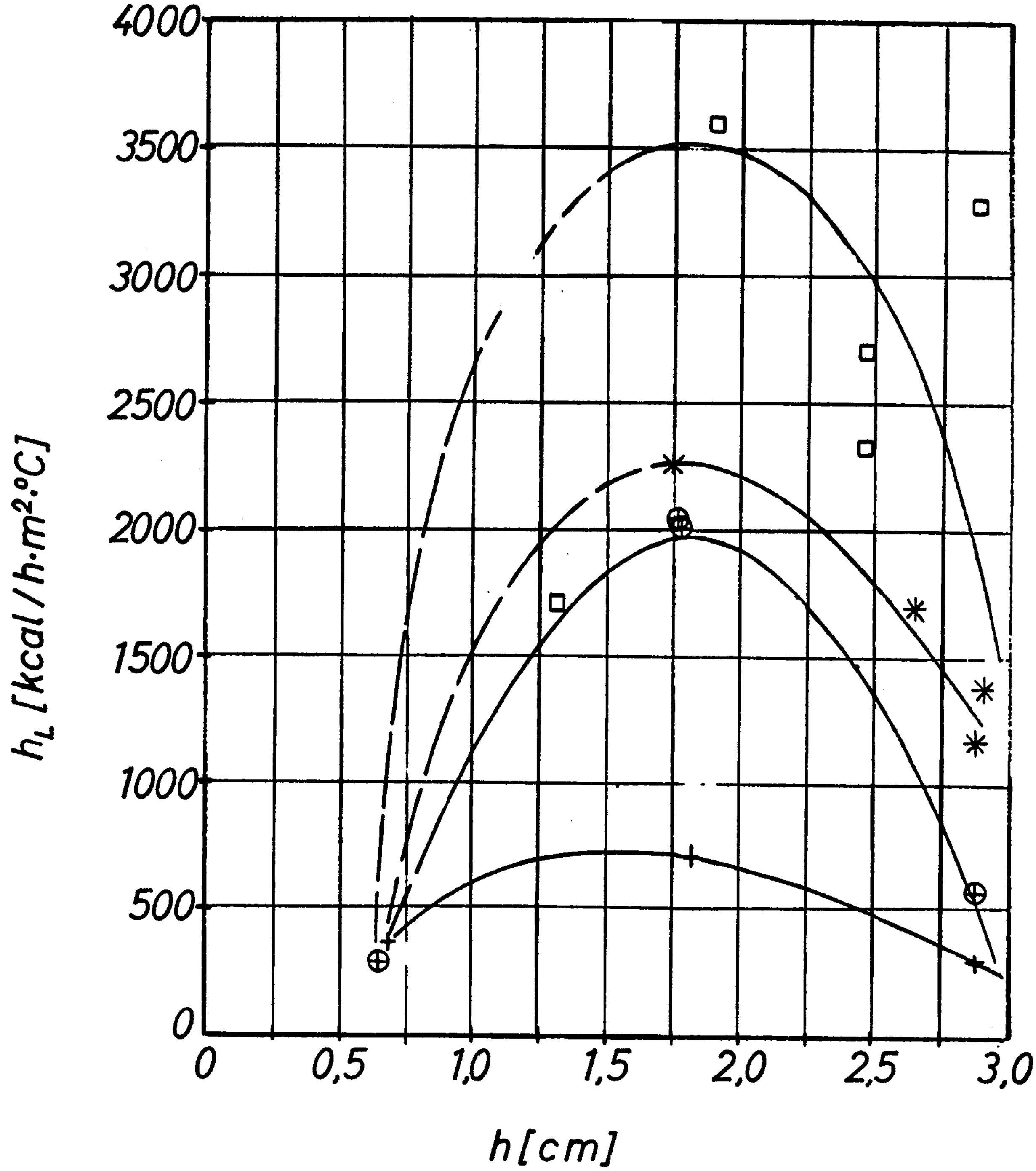
3,0
h [cm]

FIGURE 2



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2000
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1000
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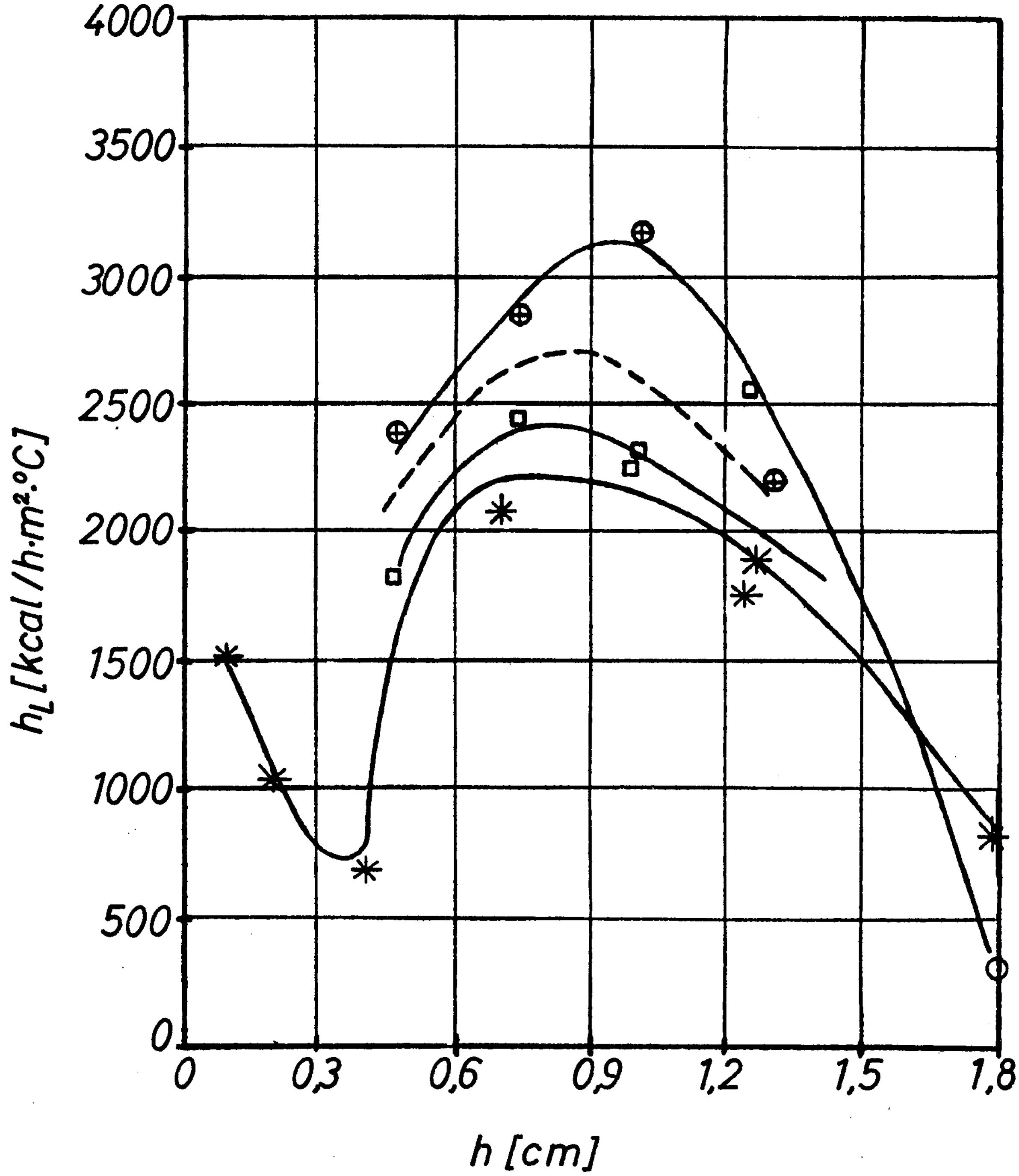
h[cm]

FIGURE 3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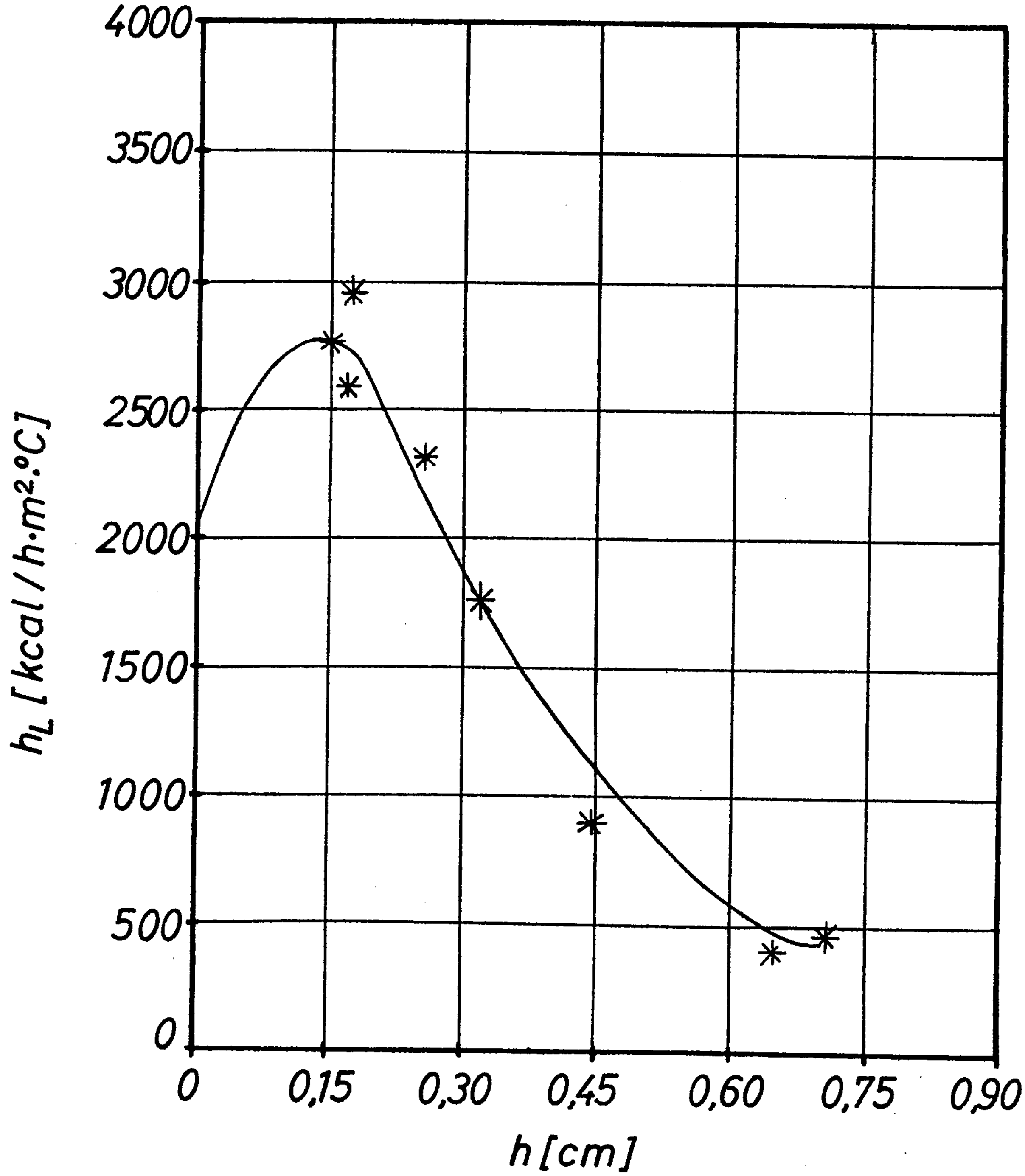
1,5
1,8
h [cm]

FIGURE 4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500
0
h_L [kcal / h·m²·°C]
0
0,15
0,30
0,45
0,60
0,75
0,90
h [cm]

FIGURE 5