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(54) **High pressure sodium lamp having improved efficacy.**

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Description

This invention is concerned with high efficacy high pressure sodium (HPS) arc discharge lamps as disclosed e.g. in US—A—39 06 272. Such lamps have a non-vitreous, for example alumina, art tube having electrodes at its ends and containing sodium, mercury, and a starting gas. The invention is particularly concerned with improving the efficacy of such lamps by design changes which reduce the wall loading, and reduce the average arc current density while simultaneously maintaining the wall temperature above about 1100°C.

Background of the invention

It is well known in the prior art that the useful visible radiation from an arc discharge in a mixture of sodium and mercury vapors is only one of several modes of energy dissipation by such arcs. In order to optimize the efficacy of a high pressure sodium lamp incorporating such an arc, it is necessary to minimize all the non-useful modes of energy dissipation as a result of the collective effects of such variables as arc temperature, sodium and mercury pressures, power input per unit length, tube diameter and tube wall temperatures. As a result of such determinations, we have found that the present designs of HPS lamps, optimized for diameter, wall loading, sodium and mercury pressures by empirical techniques known to the prior art, suffer from a number of intrinsic compromises that have hitherto been unsuspected by the most knowledgeable workers in the field. For instance, we have found that, at constant power input and sodium pressure for a given size tube, efficacy increases with increasing wall temperature by 6 to 10% per 100K. The reason for this increase is that self-absorption of sodium D line radiation in the self-reversed portion of the line is decreased at constant sodium pressure as wall temperature T_W increases, because the density of neutral sodium atoms in the cooler gas near the walls decreases as T_W increases, according to P_{Na}/kT_W, where P_{Na} is the sodium vapor pressure and k is Boltzmann's constant. In Figure 1 is shown as a shaded area in a spectral power distribution the additional radiation which is emitted (at a constant art temperature and sodium vapor pressure) at 1500K wall temperature in comparison to 1300K. Simultaneously, the loss of energy per unit area from the arc by conduction of heat to the wall decreases as T_W increases, since the temperature gradient between the arc and the wall decreases. Figure 2 illustrates the measured dependence of efficacy as a function of arc tube wall temperature determined from an experiment in which the wall temperature of a lightly-loaded arc tube was varied by operating it inside an independently controllable furnace.

Accordingly, if all other factors were held constant, this factor would cause the efficacy to increase as wall loading (power/unit area of external wall surface) is increased, because wall temperature increases as wall loading increases. High wall loadings are best achieved by operating at high power input per unit of arc length in tubes of small wall diameter. This has tended to dictate empirically developed designs of HPS lamps operating at or above about 14 watts/cm^2 of wall loading, requiring power input per unit of arc length of about 30 watts/cm or greater and tube inside diameters typically less than 1 cm.

The arc temperatures which result from such conditions of operation are typically of the order of 4000K, and increase with increasing power per unit length. As a result of our researches, we have determined that the dependencies on arc temperature of two of the major useless radiative energy-loss mechanisms of the arc (infrared line emission and infrared continuum emission) are substantially greater than that of the useful visible emission in the sodium D lines. Accordingly, as arc temperature increases, these two useless energy loss mechanisms increase faster than the desired sodium D emission, decreasing the ratio of useful visible to non-useful infrared, and with it the efficacy. Accordingly, at constant wall temperature, constant sodium pressure and constant tube diameter, efficacy would decrease with increasing power per unit length, and therefore wall loading. Correspondingly, from this factor, efficacy would increase as the power per unit length and the arc temperature decrease.

Immediately, therefore, we now recognize an intrinsic compromise inherent in lamps of the prior art. One factor increases efficacy with increasing power per unit length and wall loading; another decreases efficacy with increasing power per unit length and wall loading. It has never been possible to take advantage of the separate effects of increased efficacy at reduced power per unit length, and increased efficacy at higher wall temperature, since in prior art lamps power per unit length and wall temperature have been inexorably tied together. In fact, since the wall temperature effect is somewhat larger than the power/unit length effect, the net result in any practical prior art lamp has been an efficacy which slowly increases with power per unit length up to the maximum permitted by the temperature capability of the arc tube material, when measurements are made at optimum sodium pressure.

The empirical dependence of efficacy on sodium pressure at constant tube diameter and power per unit length is well known to the prior art, and results in a maximum efficacy at that sodium pressure for which the separation between the red wing and blue wing maxima of the self-reversed sodium D line is 8 to 10 nm. This in turn results from the competition of two effects, to wit: as sodium pressure decreases toward very low levels, the lumens per radiated watt of sodium D radiation approaches a constant 525 lumens/watt; however, the total sodium D radiation decreases with decreasing sodium pressure, and hence overall efficacy decreases. On the other hand, at sodium pressures above the optimum, the concomitant broadening of the sodium D line results in increasing of this radiation in the far red and near infrared, to which the eye is insensitive. Accordingly, the average lumens per radiated watt of sodium D radiation decreases toward 300 lumens/watt. The total fraction of input energy radiated in the sodium D line tends to approach a saturation value with increasing sodium pressure, however; consequently the overall lamp efficacy must decrease with increasing sodium pressure in this domain. The maximum of lamp efficacy then is found at an optimum pressure intermediate to the "low" and "high" pressure domains.

As a consequence of our researches, we have found that the optimum sodium pressure for maximum efficacy depends on tube diameter (d) in the following way. Maximum efficacy is found at a D line separation of 8 to 10 nm, independent of diameter, but the sodium pressure P_{Na} required to yield this D line separation decreases with increasing diameter according to the expression, P_{Na} is proportional to $1/\sqrt{d}$. We further find that the various modes of energy loss from the arc depend on sodium pressure and tube diameter at constant arc and wall temperatures in the following way:

sodium D radiation per unit length of arc is proportional to $P^2_{Na}d^2$;
infrared lines per unit length of arc is proportional to $P_{Na}d^{3/2}$;
infrared continuum per unit length of arc is proportional to $P^2_{Na}d^2$; and
heat conduction loss per unit length of arc is approximately independent of P_{Na} and d.

When P_{Na} is restricted to its optimum value, varying as $1/\sqrt{d}$, the diameter dependencies of the varying modes of energy dissipation at constant arc and wall temperature are:

sodium D radiation per unit length of arc is proportional to d;
infrared lines per unit length of arc is proportional to d;
infrared continuum per unit length of arc is proportional to d; and
heat conduction loss per unit length of arc is approximately independent of d.

We see, therefore, that the fraction of input energy dissipated by heat conduction to the arc tube wall, which amounts in a typical 400 watt HPS lamp of the prior art to approximately one-third of the input power, may be effectively reduced by the use of larger diameter arc tubes; all radiation losses increase with diameter, while heat conduction loss remains constant, and thereby becomes a smaller fraction of the total. Since it is a major non-luminous energy loss, when the heat conduction fraction is decreased, luminous efficacy must increase, i.e., luminous efficacy increases with increasing tube diameter (provided sodium pressure is adjusted to the optimum value at each diameter).

Immediately, of course, we again see an intrinsic compromise forced on the lamp designer that has hitherto gone unrecognized by specialists in the field. As tube diameter is increased, the heat input to the wall required to maintain a constant temperature should increase in proportion to diameter; but as we have seen, the heat conduction from the arc, a major component of that heat input, remains constant. Consequently, without any special measures to improve heat insulation of the wall, the wall temperature will decrease as the tube diameter increases. Because of the already-described large dependence of efficacy on wall temperature, the decrease in wall temperature with increasing tube diameter wipes out and reverses the gain which would have been observed at constant wall temperature.

Moreover, we note that it is of no value to attempt to maintain the wall temperature constant by simultaneously increasing the power input/unit length as diameter is increased. This results in a greater increase in the useless infrared lines and continuum than in the visible sodium D line, because of the increase in arc temperature required and the higher temperature coefficients of the former.

As a consequence, the effects of power per unit length and tube diameter on efficacy uncovered by our researches have in practical lamps been negated by the inverse effects of wall temperature and have remained undiscovered by the many specialists throughout the world attacking the problem of design of HPS lamps by the usual empirical techniques.

The results of our investigations can be summarized as follows.

1. Luminous efficacy increases with increasing wall temperature (all other factors held constant) because of reduced self-absorption of radiation in the center of the sodium D line. Each additional watt of radiation permitted to escape in this region of the spectrum contributes about 500 lumens to the total luminous output.

2. Luminous efficacy increases as power input per unit length decreases below that of prior art lamps (all other factors held constant) because useless infrared radiation is decreased thereby to a greater degree than the useful sodium D radiation. It is to be noted that this increase in efficacy with decrease in power per unit length does not continue indefinitely to vanishing power per unit length. The continuing increase in efficacy is limited and eventually reversed by the fact that the heat conduction loss itself has a lower coefficient of dependence on arc temperature than any radiation loss. At some low power per unit length the energy loss due to heat conduction becomes too large in comparison to the desired D line radiation, thus limiting and reversing the increase in efficacy. There is therefore an optimum power per unit length which is in the vicinity of 20 to 25 watts/cm, substantially lower than the operating values of many prior art high pressure sodium lamps.

3. Luminous efficacy increases as tube diameter increases (sodium pressure adjusted for optimum, all other factors held constant) because useless heat conduction loss is reduced relative to the useful radiation loss.

The several energy losses, their functional dependencies and appropriate magnitude coefficient have been incorporated in a simple energy balance to yield the result shown in Figure 3, which is a plot of efficacy (normalized to that of the prior art 400 watt lamp, 0.7 cm in inside diameter) vs power input per unit length, with tube diameter as a parameter; constant wall temperature and optimum sodium pressure for each diameter is assumed. In this simplified energy balance picture, the change in the shape of radial temperature profile of the arc with diameter is neglected; when this factor is included in a more detailed calculation, the increase of efficacy with diameter is not quite as large, but the trend is identical. The existence of a maximum in efficacy at an optimum power per unit length is clearly visible in these calculations; the optimum power per unit length appears to be in the vicinity of 20 to 25 watts/cm, substantially below the values of many prior art lamps.

The concepts and principles stated herein are at variance with the prior art understanding of the means of optimizing high pressure sodium lamps for maximum efficacy. For example, above-mentioned US—A—39 06 272 discloses, in figure 1, an optimum arc tube inside diameter for each wattage lamp and design center arc drop; the patent does not recognize that said optimum diameter results from two competing mechanisms which we have discovered and disclose herein. We have discovered that with suitable thermal insulation to maintain wall temperatures sufficiently high, efficacy continues to increase with increasing diameter up to at least double the diameters disclosed in said patent to be optimum.

Accordingly, it is an object of this invention to provide a high pressure sodium vapor lamp of the type disclosed e.g. in US—A—39 06 272 and comprising a non-vitreous arc tube having electrodes at its ends and containing sodium, mercury, and a starting gas, which has a higher efficacy as heretofore attainable. This object is achieved, in accordance with the invention, by modifying the lamp such that the lamp includes means to maintain the arc tube wall temperature greater than about 1100°C at the central section, and to maintain the temperature of the sodium-mercury amalgam reservoir at the value yielding optimum sodium vapor pressure, and that during normal operation the wall loading is less than about 13 W/cm^2 of arc tube external wall surface, and the current density is less than about 8 A/cm^2 of arc tube internal cross sectional area.

With the low wall loading and current density taught by the invention in contrast to the prior art, it may become difficult to maintain the arc wall temperature above the indicated level (which is well in agreement with the prior art), and thus it may be necessary to provide means for increasing the operating wall temperature of any HPS lamp which is less than the maximum permitted by the arc tube material (about 1500K for polycrystalline alumina), thereby permitting an increase in efficacy of about 6 to 10% per 100K increase in wall temperature. The operating wall temperature may be increased by improved thermal insulation of the arc tube or by a reduction in primary thermal radiation and/or heat conduction of the arc tube material. Means should be provided to maintain the sodium-mercury amalgam reservoir temperature at the value yield optimum sodium vapor pressure.

In a lamp including an outer jacket surrounding the arc tube, therefore, preferably means thermally insulating the arc tube are disposed within or upon the inner surface of said outer jacket. In one embodiment said thermally insulating means is an infrared reflective coating of indium oxide and tin oxide, and preferably such a reflective coating is disposed on the inner surface of a sleeve surrounding the arc tube within said outer jacket.

In accordance with the invention, the means for increasing the operating wall temperature are utilized to make feasible the employment of arc tubes of substantially larger diameter than prior art arc tubes, in order to achieve the efficacy gain associated with said larger diameter by keeping the wall temperature at or near the maximum permitted by the material (about 1500K for polycrystalline alumina) in spite of the reduced wall loading. Prior art arc tubes had arc tube outer diameters of about 0.6 to 1.0 cm and operated (when optimally designed) at wall loadings of about 14 to 20 watts/cm^2. Prior art arc tubes also generally operated at about 25 to 50 watts per cm of arc length; in this invention, the power consumption per cm of arc length is generally less.

To demonstrate the changes in lamp design which result from the teachings of this invention, consider a 400 watt HPS lamp, such as has been an article of commerce since the late 1960's and has not changed substantially in physical dimensions, materials of manufacture or performance ratings since about 1973. Such lamps are typically rated at 50,000 lumens, 125 lumens per watt, and do not, on the average, exceed that rating in performance. Arc tubes used by all manufacturers are substantially similar in dimensions. Thus, such lamps can be considered to have been thoroughly optimized according to the teachings of the prior art.

Brief description of the drawings.

Fig. 1 is a plot of sodium resonance radiation in terms of spectral radiant flux versus wavelength, at wall temperatures of 1300K and 1500K.

Fig. 2 shows relative efficacy as a function of arc tube wall temperature, at optimum sodium vapor pressure.

Fig. 3 is a plot of relative efficacy of HPS lamps versus input power (watts) per centimeter of arc length, at optimum sodium pressure and constant wall temperature (about 1500K), for arc tubes having inside diameters of 2.0, 1.5, 1.1 and 0.7 cm.

Fig. 4 shows an HPS lamp in accordance with this invention.

Example 1, below, illustrates the comparison between the performance of a prior art lamp and that of a lamp constructed in accordance with the teachings of this invention, employing translucent polycrystalline yttrium oxide (yttria) as the arc tube material instead of alumina.

Both translucent ceramics have the property of becoming opaque in the infrared spectral region. Alumina becomes absorbent between about 4 microns and about 7 microns wavelength, whereas yttria becomes absorbent between about 7 microns and about 9 microns; thus yttria will intrinsically thermally radiate less than alumina at temperatures about 1200°C.

The thermal radiant emittances of translucent polycrystalline yttria arc tubes, such as disclosed in U.S. Patents 4,147,744 and 4,115,134, have been measured to be about 0.11, while those of polycrystalline alumina are typically 0.20. This permits the yttria arc tube to reach a higher wall temperature for a given power per unit area dissipation or, more importantly for our purposes, to achieve equal temperature to an alumina arc tube wall at a lower power per unit area. Thus we can provide a higher efficacy lamp by means of a larger diameter, lower-wall-loaded yttria arc tube maintained at equal or nearly equal temperature as an arc tube designed according to the prior art.

	Example 1 This invention	Prior art
Arc drop, volts	94.2	100. (typical)
Current, amperes	4.84	4.7 (typical)
Diameter ID, cm	1.209	0.732
Arc length, cm	10.12	8.4
Current density*, amp/cm^2	4.22	11.17
Wall loading, watts/cm^2 OD	9.11	17.05
Arc loading, watts/cm arc length	39.5	47.6
Wall temperature, °C	1090.	1200. (typical)
Lumen output	52720.	49000. (typical)
Efficacy, LPW	132.	123.
% Improvement	7.6	

*Averaged over the internal cross section.

Note the substantial reduction in both current density and wall loading of this lamp in comparison to the prior art lamp, and the substantial increase in efficacy despite a somewhat lower wall temperature. It is noted that US—A—3 906 272 does not disclose an optimum diameter for a prior art 400 watt lamp. However, an extrapolation of the curves therein to the 400 watt level confirms that 0.732 cm can be considered very nearly optimum according to the prior art.

The wall temperatures cited above and elsewhere in this specification are measured by a radiometric method described by deGroot, J. J., "Comparison Between the Calculated and the Measured Radiance at the center of the D-lines in a High Pressure Sodium Vapor Discharge", Proc. 2nd IEE Conference on Gas Discharges, London, p. 124 (1972). This method is believed to have an accuracy of plus or minus 20 to 30°.

Example 2 shows the results for a 150 watt 55 volt HPS lamp made in accordance with this invention as compared to a 150 watt 55 volt HPS prior art lamp. The lamp as per this invention had an 8 mm inside diameter yttria arc tube while the prior art lamp had a 5.87 mm inside diameter alumina arc tube, which is very close to the diameter of 5.75 mm disclosed in US—A—3 906 272 to be optimum for this lamp.

	Example 2 This invention	Prior art
Arc drop, volts	57.2	55. (typical)
Current, amperes	3.09	3.2 (typical)
Diameter ID, sm	0.8	0.587
Arc length, cm	4.98	4.02
Current density*, amp/cm^2	6.15	11.83
Wall loading, watts/cm^2 OD	9.83	16.07
Arc loading, watts/cm arc length	30.12	37.3
Wall temperature, °C	1120.	1150. (typical)
Lumen output	16670.	15250. (typical)
Efficacy, LPW	111.	102.
% Improvement	9.3	

*Averaged over the internal cross section.

There is a substantial reduction in both current density and wall loading of this lamp in comparison to the prior art lamp, and it has higher efficacy as well, even though the diameter is 39% greater than the diameter disclosed in US—A—3 906 272 to be optimum. The efficacy gain for the lamp of Example 2 is greater than that for Example 1 because the wall temperature of the new lamp in Example 2 is closer to that of the prior art lamp.

Example 3 shows the comparison in efficacy between a 50 watt lamp according to our invention employing an yttria arc tube for reduced thermal radiative losses, and two different versions, A and B of 50 watt prior art lamps. Prior art lamp A has been manufactured for only about a year and has been known to not have been optimized according to the known prior art, by virtue of its very low wall loading and low arc tube wall temperature. Experimental lamps manufactured according to our invention with yttria arc tubes of identical dimension have substantially increased arc tube wall temperatures and correspondingly increased efficacy. Recently announced prior art lamp B represents an attempt to further optimize the 50 watt lamp according to the known prior art principles, viz., by decreasing the arc tube diameter, shortening the arc length, increasing the wall loading.

Example 3

	This invention	Prior art lamp A	Prior art lamp B
Arc tube	yttria	alumina	alumina
Arc drop	54.	52.	52.
Current	1.11	1.18	1.18
ID (cm)	0.477	0.477	0.378
Arc length (cm)	3.08	3.08	2.09
Current density* (a/cm^2)	6.21	6.60	10.51
Wall loading (W/cm^{2}OD)	8.14	8.14	16.04
Arc loading (W/cm)	16.23	16.23	23.92
Wall temperature	1110°C	1000°C	1085.
Lumen output	3950.	3400.	4000. (nominal)
Efficacy	79.	68.	80.
% Improvement	16.	—	—

*Averaged over the internal cross-section.

Optimum diameter for this lamp according to US—A—3 906 272 is 0.335 cm. It should be noted that despite a deviation of more than 40% from said optimum diameter, the lamp according to our invention has equivalent efficacy. Moreover, prior art Lamp A was deliberately designed at less than optimum wall loading for alumina in order to improve its lumen maintenance and ease of manufacture, advantages which are retained by our lamp but are lost in the more recent prior art lamp B.

Thus far, the specific examples used to illustrate this invention have been employed yttria arc tubes. However, other means to reduce thermal radiative losses may also be used to provide the larger diameter, lower wall loading, lower arc current density arc tubes that are the subject of this invention, and that have an arc tube surface wall temperature above about 1100°C., preferably near 1200°C, in spite of reduced heat input per unit area to the arc tube walls.

In example 4, below, we describe the use of infrared-reflecting shields to reduce thermal radiative losses.

Example 4

A conventional 400 watt lamp was constructed with an alumina arc tube, 7.3 mm inner diameter by 8.9 mm outer diameter, inside the usual type 7720 glass outer jacket. However, a quartz sleeve, 29 mm inner diameter by 33 mm outer diameter, surrounded the arc tube within the outer jacket. On the inner surface of the quartz sleeve was an infrared reflective coating of indium oxide and tin oxide. Lamp operation is summarized below.

Power	400 watts
Arc tube wall temperature	1257°C
Separation of D line peaks	52 angstroms
Efficacy	123.8 LPW
Efficacy corrected for 10% wall reflection loss	136 LPW

At 400 watts the wall temperature is higher than 1200°C normally associated with the conventional 7.3 mm I.D. design. Thus the quartz sleeve will permit the use of larger diameter on tubes. However, the use of such a sleeve provides two additional glass interferences which the light emitted by the arc tube has to pass through. A large percentage of the reflected radiation from the glass interferences is then lost through absorption within the lamp. If the observed efficacy of about 124 LPW is corrected for this loss, we see that the efficacy of the arc tube has increased substantially above that of the same arc tube mounted without heat conserving means, and is in fact, substantially greater than the 125 LPW obtainable from prior art 400 watt lamps. This increase in efficacy has resulted from the reduction in self-absorption of the sodium D radiation brought about by the lower sodium atom density near the wall that is a consequence of the higher wall temperature.

In Example 5, below, we describe the application of the radiant-reflector principle of thermal insulation to an arc tube with a larger diameter.

Example 5

A lamp (Lamp C) was made comprising a large diameter alumina arc tube, 11.0 mm I.D. by 12.5 mm O.D. within a cylindrical type 7720 glass outer jacket. There was an infrared reflective coating, similar to that of Example 4, on the inner surface of the jacket. Performance of Lamp C was compared with that of a similar lamp (Lamp D) without the infrared reflective coating (but with niobium heat shields at the arc tube ends to raise the end temperature, therefore the pressure, of the sodium-mercury amalgam). Performance of the lamps is summarized below.

	Lamp C			Lamp D	
Power, watts	400	650	700	400	700
Arc tube wall temperature, °C	1035		1200	990	1035
Separation of D line peaks, angstroms	25	55	64	28	54
Efficacy, LPW	111.0	137.0	139.1	106.3	103.4

These results show that the infrared reflective coating raises the arc tube temperature. A comparison of lumens at similar D lines indicates the advantage gained from the increase in wall temperature. Conventionally designed lamps operate at 125 LPW at 400 watts and 135 LPW at 1000 watts. Comparison with Lamp C at 700 watts indicates that higher efficacies can be obtained by this invention than by utilizing conventional methods of HPS lamp design, Lamp C having higher efficacy at 700 watts than conventional lamps at 1000 watts.

As a further illustration of the degree to which our invention differs from the precepts of HPS lamp-design embodied in the prior art, we offer the data in Table I which shows the dimensions, average arc current density, wall loading, and arc loading for a number of high pressure sodium lamps, encompassing all wattages above 70 watts presently commercially available, designed according to the teachings of the prior art, where

$$\text{current density} = I/\pi \left(\frac{ID}{2}\right)^2,$$

wall loading=P/(π×OD×AL) and arc loading=P/AL, where I=lamp current, P=lamp power, AL=distance between electrode tips and ID, OD=inside and outside diameters respectively.

TABLE I

Power, watts	Volts	Current, amps	Diameter, ID	Centimeter OD	Arc length, cm	Current density, amp/cm^2	Wall loading, watts/cm^2	Arc loading, watts/cm arc length	Lumens per watt (nominal)	Wall temperature °C
100	55	2.1	.477	.635	2.8	11.78	17.80	35.71	95	1128
150	55	3.2	.587	.739	4.02	11.83	16.07	37.31	107	1137
150	100	1.8	.477	.635	5.18	10.08	14.51	2.96	107	1171
200	100	2.4	.587	.739	5.25	8.87	16.41	38.10	110	
250	100	3.0	.732	.889	6.13	7.13	14.60	40.78	110	1153
250S	100	3.0	.587	.739	5.54	11.09	19.44	45.13	120	
310	100	3.6	.662	.813	7.03	10.46	17.26	44.10	119	
400	100	4.7	.732	.889	8.4	11.17	17.05	47.62	125	1185
1000	250	4.7	.732	.889	20.69	11.17	17.31	43.30	135	1197

An important point to notice is the comparison between the 250 and 250S lamps, the latter having been optimized for higher efficacy over the former according to the teachings of the prior art. The 250 watt lamp has a wall loading of 14.6 watts/cm^2, an ID of 0.732 cm and delivers about 26500 lumens, while the 250S lamp has a wall loading of 19.44 watts/cm^2, an ID of 0.587 cm and delivers about 29000 lumens. According to US—A—3 906 272, the optimum diameter for this lamp is approximately 0.55 cm. Thus, the direction of change of dimension parameters for increased efficacy according to the teachings of the prior art is toward smaller diameter arc tubes, with a resulting increase in wall loading. That teaching is directly opposite the disclosure of this invention.

The lamps in Table I are typically designed for maximum efficacy according to the teachings of the prior art. None of the lamps are designed with a diameter large enough that the current density is as low as 8.0 amp/cm^2. Nor are any of the lamps designed with a wall loading as low as 13 watts/cm^2. Moreover, the efficacies indicated appear generally to increase with increasing wall temperature, and all wall temperatures appear to be in excess of about 1100°C. Thus, we may conclude that the optimum diameters cited in US—A—3 906 272 for each lamp simply represent the largest possible diameter consistent with a minimum wall temperature of 1100°C for conventionally constructed high pressure sodium lamps.

To repeat once more, the central concept of our invention is that still higher efficacies can be obtained at still larger diameters when suitable steps are taken to reduce the thermal radiative losses from the arc tube surface so that its temperature can be maintained above 1100°C even though the heat energy input per unit area of wall surface may be reduced.

In a preferred embodiment, a lamp in accordance with this invention comprises a non-vitreous arc tube 1 having electrodes 2 sealed into the ends. Arc tube 1 contains sodium, mercury and a starting gas, typically, xenon. A metal framework 3 provides support for the arc tube and an electrical path to the upper electrode. A support wire 4 is embedded in glass press 5 and provides electrical connection to the lower electrode. The arc tube assembly is contained within an outer glass jacket 6. Arc tube 1 was made of yttria and the results for a 150 watt lamp and a 400 watt lamp made in accordance therewith are shown in Examples 2 and 1 above, respectively.

Claims

1. High pressure sodium arc discharge lamp comprising a non-vitreous arc tube having electrodes at its ends and containing sodium, mercury, and a starting gas, characterized in that the lamp includes means to maintain the arc tube wall temperature greater than about 1100°C at the central section, and to maintain the temperature of the sodium-mercury amalgam reservoir at the value yielding optimum sodium vapor pressure, and that during normal operation the wall loading is less than about 13 W/cm^2 of arc tube external wall surface, and the current density is less than about 8 A/cm^2 of arc tube internal cross sectional area.

2. Lamp according to claim 1 including an outer jacket surrounding the arc tube, characterized in that means thermally insulating the arc tube are disposed within or upon the inner surface of said outer jacket.

3. Lamp according to claim 2, characterized in that said thermally insulating means is an infrared reflective coating of indium oxide and tin oxide.

4. Lamp according to claim 3, characterized in that said reflective coating is disposed on the inner surface of a sleeve surrounding the arc tube within said outer jacket.

Revendications

1. Une lampe de décharge à arc de sodium à haute pression, comprenant un tube à arc non vitreux, muni à ses extrémités d'électrodes et contenant du sodium, du mercure et un gaz d'allumage, caractérisée en ce que la lampe comporte des moyens pour maintenir la température des parois du tube à arc supérieure à environ 1100°C dans la section centrale, et à maintenir la température du réservoir d'amalgame mercure/sodium à la valeur donnant la pression optimale de vapeur de sodium, et en ce qu'au cours du fonctionnement normal, le chargement des parois est inférieur à environ 13 W/cm2 de surface de paroi externe de tube à arc, et la densité du courant est inférieure à environ 8 A/cm2 de section interne de tube à arc.

2. Une lampe selon la revendication 1, comportant une enveloppe externe entourant le tube à arc, caractérisée en ce que des moyens d'isolation thermique du tube à arc sont disposés dans ou sur la surface interne de ladite enveloppe externe.

3. Une lampe selon la revendication 2, caractérisée en ce que lesdits moyens d'isolation thermique se présentent sous la forme d'un revêtement réfléchissant infrarouge d'oxyde d'indium et d'oxyde d'étain.

4. Une lampe selon la revendication 3, caractérisée en ce que ledit revêtement réfléchissant est disposé sur la surface interne d'un manchon, entourant le tube à arc à intérieur de ladite enveloppe externe.

Patentansprüche

1. Hochdrucknatriumbogenentladungslampe mit einer nicht durchsichtigen Gasentladungsröhre, die an ihren Enden Elektroden hat und Natrium, Quecksilber und ein Zündgas enthält, dadurch gekenn-

zeichnet, daß die Lampe Mittel aufweist, um die Wandtemperatur der Entladungsröhre auf einer Temperatur oberhalb von 1100°C in einem zentralen Abschnitt zu halten und um die Temperatur des Natriumquecksilberamalgambehälters auf einem Wert zu halten, der zu einem optimalen Natriumdampfdruck führt und daß während des Normalbetriebs die Wandbelastung weniger als ca. 13 W/cm^2 an der äußeren Wandoberfläche der Entladungsröhre beträgt und daß die Stromdichte geringer als ca. 8 A/cm^2 der inneren Querschnittsfläche der Entladungsröhre beträgt.

2. Lampe nach Anspruch 1, mit einer äußeren Ummantelung, die die Entladungsröhre umgibt, dadurch gekennzeichnet, daß Mittel zur thermischen Isolierung der Entladungsröhre innerhalb oder auf der inneren Oberfläche dieser äußeren Ummantelung angeordnet sind.

3. Lampe nach Anspruch 2, dadurch gekennzeichnet, daß die Mittel zur thermischen Isolierung aus einem infrarotreflektierenden Überzug aus Indiumoxid und Zinnoxid besteht.

4. Lampe nach Anspruch 3, dadurch gekennzeichnet, daß dieser reflektierende Überzug auf der inneren Oberfläche einer Hülse angeordnet ist, die die Entlandungslampe innerhalb der äußeren Ummantelung umgibt.

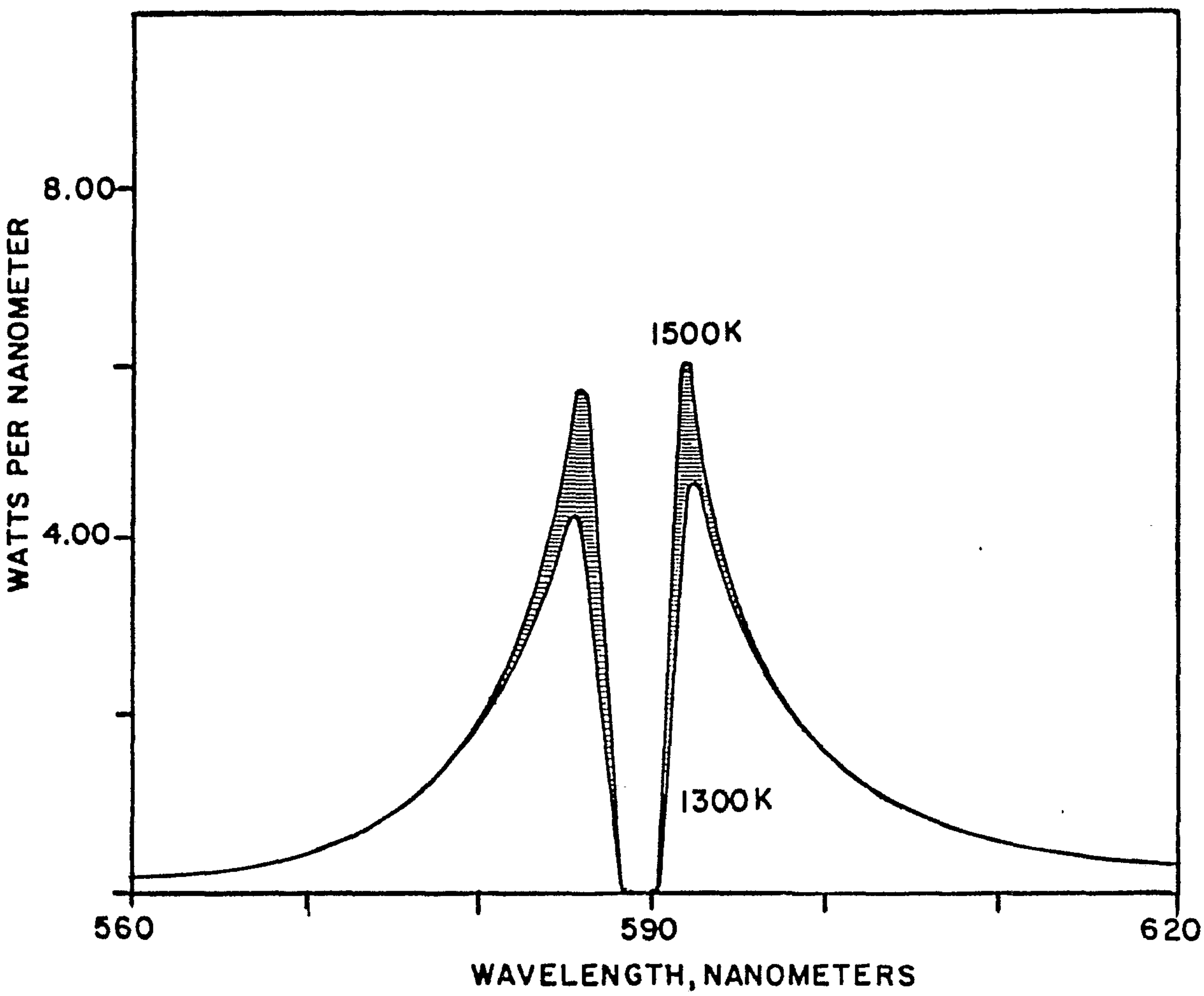

8.00
4.00
WATTS PER NANOMETER
1500K
1300K
560
590
620
WAVELENGTH, NANOMETERS

FIG.1

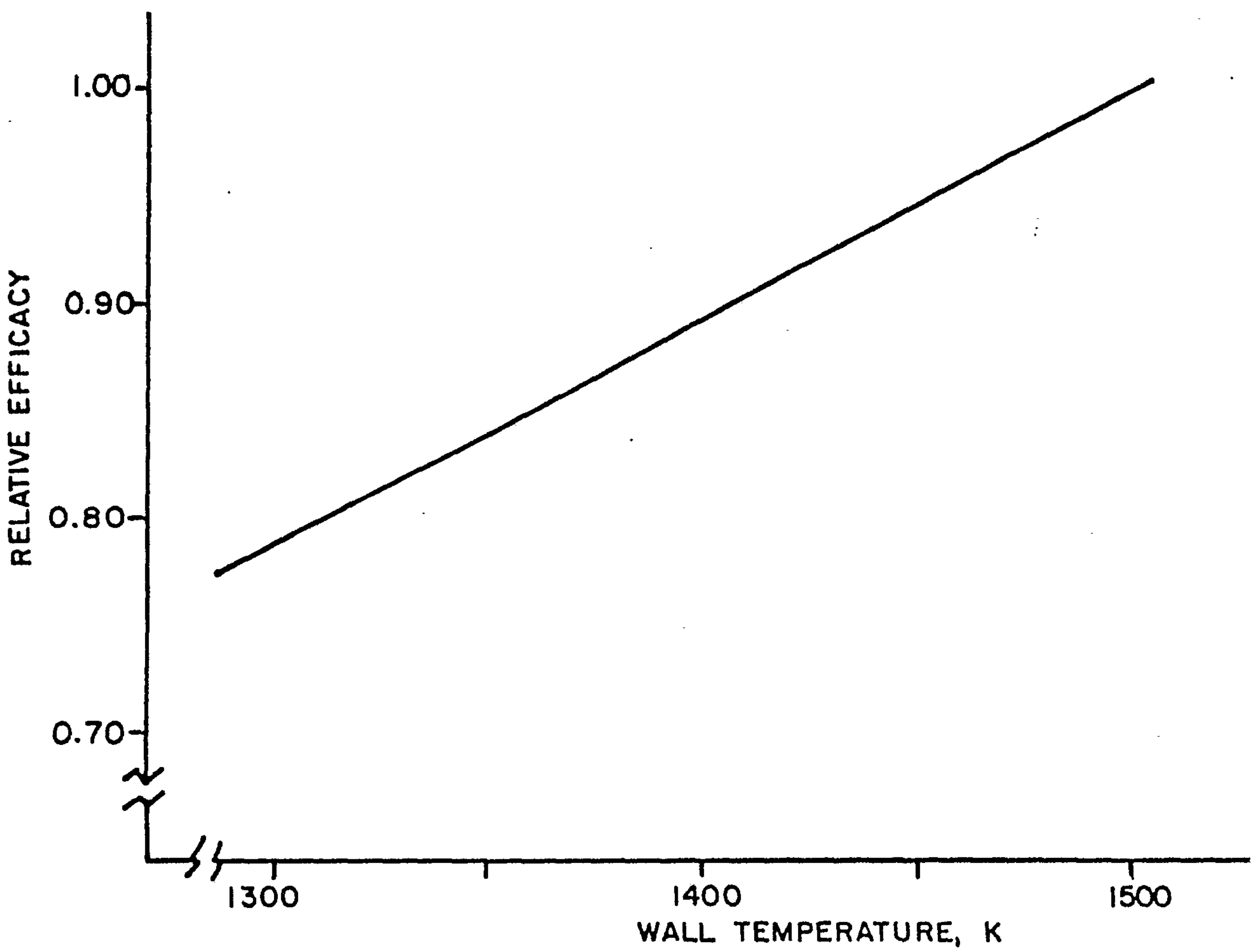
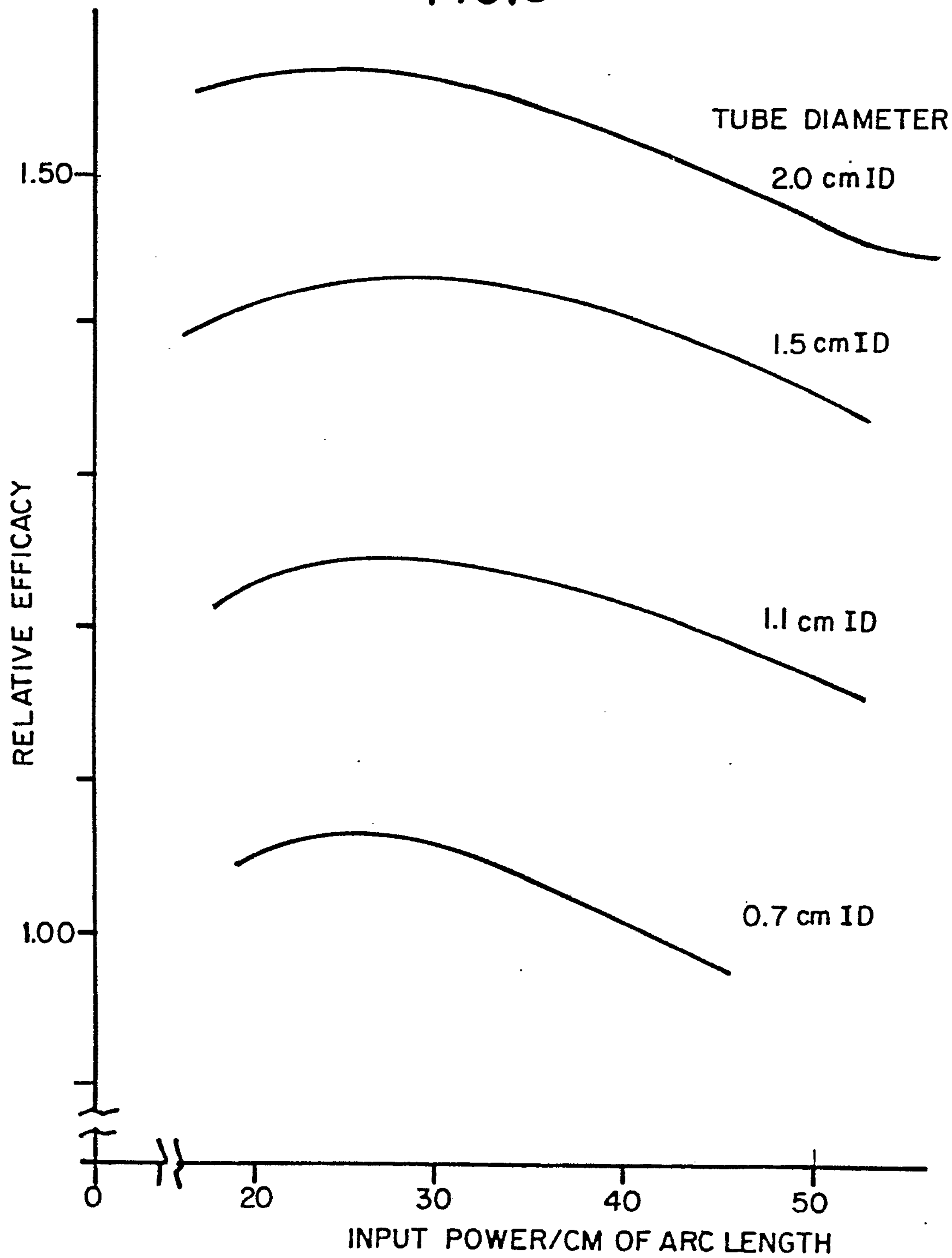

RELATIVE EFFICACY
1.00
0.90
0.80
0.70
1300
1400
1500
WALL TEMPERATURE, K

FIG. 2

FIG.3


TUBE DIAMETER
2.0 cm ID
1.5 cm ID
1.1 cm ID
0.7 cm ID
1.50
1.00
RELATIVE EFFICACY
0
20
30
40
50
INPUT POWER/CM OF ARC LENGTH

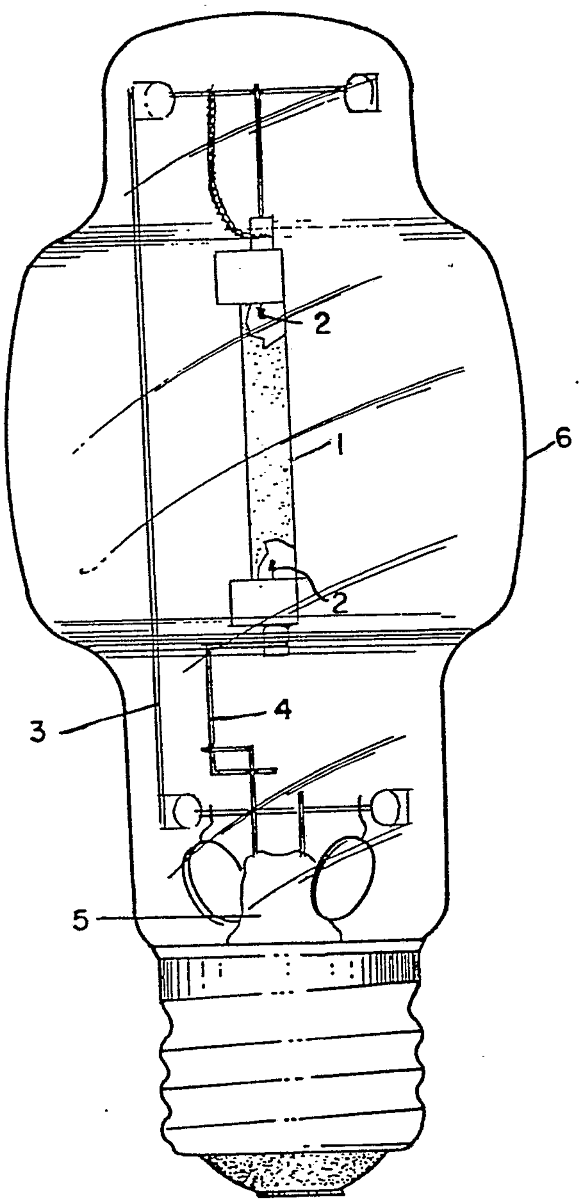


FIG.4