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RELATION OF MOISTURE CONTENT AND DRYING RATE OF WOOD TO RELATIVE HUMIDITY OF ATMOSPHERE

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
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RELATION OF MOISTURE CONTENT AND DRYING RATE OF WOOD

TO RELATIVE HUMIDITY OF ATMOSPHERE

It is well known that wet wood gives off moisture under ordinary atmospheric conditions, and that dry wood takes on moisture in damp weather. This causes a corresponding shrinkage and swelling, commonly known as "working." As a result, doors, sash, and drawers frequently stick in damp weather and become loose in dry weather. Wooden parts may check, warp, or open up at the joints when the relative humidity of the air is low, or expand excessively when it is high.

In fact, even properly seasoned wood under ordinary conditions daily takes on or gives off moisture to accommodate itself to changing atmospheric conditions. This property, which is known as "hygroscopicity," is also found in many other materials, such as paper, clothing, hay, leather, and soil.

The purpose of this article is to give information as to how the relative humidity in the atmosphere outdoors, in the dry kiln, in the woodworking shop, in the storage room, or elsewhere affects the moisture content of wood. A brief technical discussion of atmospheric humidity and how it may be accurately determined is also included. Much of this information has been obtained through the researches of the U. S. Forest Products Laboratory.

Fundamental Relation of Moisture Content of Wood to Atmospheric Conditions

The combination of water and wood may be considered a solution of water in wood, the wood being the solvent and the water the solute. There is definite limit to the amount of water that can be dissolved in the wood and when this point is reached the wood is said to be saturated. This is commonly called the "fiber-saturation point." The vapor pressure at this time equals the saturate vapor pressure at the existing temperature, and therefore the wood is at equilibrium with 100 percent relative humidity. As the amount of water in the wood-water solution decreases the vapor pressure decreases; hence, the wood is at equilibrium with lower relative humidities. This relationship is shown by the curves in Figure 1. These curves were constructed from data obtained on Sitka spruce, but are in general applicable to all species. For example, wood exposed to a relative humidity of 60 percent at 160° F. will finally attain a moisture content of approximately 8 percent. It is interesting to note that changes in relative humidity are more critical on moisture content than are changes in temperature.

Significance of Relative Humidity in Air Drying Wood

In air drying, lumber finally reaches a definite moisture condition below which it does not go, no matter how long it is kept on stickers, provided the atmospheric conditions remain fairly constant. Black walnut, after being stored in an unheated shed for 60 years at the Rock Island Arsenal, had a moisture content of 11.6 percent, based on the oven dry weight.

The moisture content of small blocks (1-1/2 by 1-1/2 by 8 inches) air-dried under cover in an open shed at New Haven, Conn., for over a year, is given in Table 1:

Table 1.--Moisture content of small blocks throughly air seasoned at New Haven, Conn.

	Moisture content Percent
Longleaf pine	13.3
Loblolly pine	14.7
Red spruce	15.0
Eastern white pine	13.4
California red fir	14.1
White ash	14.4
Hard maple	14.9
Red ash	14.9
Sweetgum	14.9
Chestnut	13.8

In a drier climate these specimens would have dried down to a lower moisture content, and in a damp climate they would not have become so dry. Wood thoroughly air dried in the humid parts of France and England is said finally to reach from 15 to 17 percent moisture.

Table 2 shows how the relative humidity varies with the seasons in different parts of the United States. In general, the outdoor relative humidity is highest in winter and lowest in spring, although exceptions occur in some parts of the country. By means of the curves in Figure 1, the ultimate dryness of small pieces of wood during the different seasons and in various parts of the United States may be estimated. For example, at Seattle, Wash., the ultimate dryness of pieces of wood unprotected from the weather, except from snow and rain, will be reached in the winter and will be at about 19 percent moisture, whereas in western Texas, it will be reached in the spring and will be about 6 percent moisture.

This seasonal and geographic variation in relative humidity is important in connection with the rate at which drying proceeds. Lumber exposed to the spring and summer atmosphere will dry most quickly, principally because of the comparatively low relative humidity at that time of the year, but also because of the warmer temperature. For example, railroad ties, of ponderosa pine, cut in May and June at Pecos, N. Mex., were practically seasoned in 1 month, while those cut in November and December required about 6 months for seasoning. On the other hand, winter-cut lumber suffers less from checking and other defects during air seasoning. Drying is slow at first and when spring comes the lumber is already partly dry, so that deterioration is not great. Furthermore, in any climate with a high relative humidity and warm temperature, lumber is more subject to infection with stain and decay-producing organisms than it is in drier climates.

Table 2.--Average relative humidities over a period of at least 15 years at different seasons in various parts of the United States*

Mean relative humidity, percent	New York City	Cleveland, Ohio	Madison, Wis.	Bismarck, N. D.	Havre, Mont.	Spokane, Wash.
Winter.............	73	77	82	73	79	82
Spring.............	70	72	70	68	66	61
Summer.............	74	70	71	65	56	47
Fall...............	75	74	75	71	68	67
Annual mean........	73	73	74	69	67	64

Mean relative humidity, percent	Seattle, Wash.	Portland, Ore.	Salt Lake City, Utah	Denver, Colo.	Kansas City, Mo.	Memphis, Tenn.	Washington, D.C.
Winter	83	84	73	54	75	74	72
Spring	73	72	52	51	69	69	69
Summer	69	67	36	49	70	75	75
Fall	81	79	51	46	68	71	76
Annual mean	76	75	53	50	71	72	73

Mean relative humidity, percent	Chattanooga, Tenn.	Wilmington, N. C.	Jacksonville, Fla.	Pensacola, Fla.	New Orleans, La.	Galveston, Tex.
Winter	75	78	80	80	79	84
Spring	70	78	74	77	75	82
Summer	78	83	80	79	78	79
Fall	77	81	83	75	77	78
Annual mean	75	80	79	78	77	81

Mean relative humidity, percent	El Paso, Tex.	Phoenix, Ariz.	San Diego, Calif.	San Francisco, Calif.	Sacramento, Calif.
Winter	45	47	74	79	80
Spring	27	32	78	79	71
Summer	41	32	81	84	61
Fall	46	41	78	80	66
Annual mean	40	38	78	80	69

*From Weather Bureau Bull. Q, "Climatology of the United States."

The effect of differences in locality on the drying rate is also very marked, even in the same latitude. For example, while the ponderosa pine ties at Pecos, N. Mex., seasoned in 1 month, shortleaf and loblolly pine ties cut at the same time of year in eastern Texas required from 3 to 4 months for seasoning. This was due principally to differences in the relative humidity, Pecos being in a comparatively dry region, whereas the climate in eastern Texas is more humid.

Relative Humidity in Connection with Kiln Drying and Conditioning of Lumber

Although the relative humidity has an important effect on the drying rate of a pile of lumber being air seasoned, this effect is less when lumber is kiln dried. The rate of air circulation within a pile of lumber being air seasoned is low, consequently air entering at a high relative humidity rapidly approaches saturation and greatly decreases its capacity for drying. The circulation of air within a pile of lumber in a dry kiln is usually much greater than that in an air-seasoning pile, and therefore air entering at a high relative humidity does not approach so near saturation before it leaves the pile. The chief functions of relative humidity in the kiln drying of lumber are the regulation of the surface dryness and the regulation of the ultimate moisture content to which the lumber will dry.

During the early stages of drying in a kiln, a comparatively high relative humidity is used, especially if the lumber is green, so as to prevent the surface from reaching too low a moisture content, with resultant checking and casehardening. This must be accompanied by good circulation otherwise the atmosphere within the pile will rapidly approach saturation. Toward the end of the drying, when there is less danger of injury, a comparatively low relative humidity may be used in order to dry the lumber to the desired final moisture content.

If it is desirable to condition lumber for the relief of casehardening stresses during the kiln drying process, the relative humidity can be so manipulated that the surfaces absorb moisture while the center is still drying.

The seasoning of lumber which is not to be dried to a low average moisture content may be hastened by drying the surface layers down to a lower moisture content than is ultimately desired. The kiln drying operation may be stopped before the center has reached the desired moisture content because the moisture will continue to move from the wetter center to the drier surface layers until the desired ultimate average moisture content has been reached.

Relative Humidity in Storage Sheds, Shops, and Buildings in General

From what has already been said it will be seen that by properly controlling the temperature and the relative humidity of the surrounding air, seasoned lumber may be kept at any desired moisture content. For example, flooring stored in a shed may be kept at about 8 percent moisture indefinitely if the relative humidity is held at about 42 percent when the temperature is around 70° and slightly higher at higher temperatures and lower at lower temperatures. (See Fig. 1.) In factories making furniture and other wooden products requiring a low moisture content, particular care should be taken to keep the doors and windows closed in damp weather. On the other hand, in winter when the air is heated, it may be advantageous to raise the humidity artificially to at least 30 percent. The same principle applies also to storerooms in which the finished articles are kept.

One source of trouble in plants manufacturing wooden products which must meet exacting demands lies in not keeping the relative humidity fairly constant throughout the plant. For example, the dry lumber may be stored in a room where the temperature is 60° F. and the relative humidity 60 percent. Under such conditions the moisture content of the lumber will tend to go up to 11 percent. This lumber may then be taken into the shop and worked up at 70° and a relative humidity of 49 percent. As a result, the moisture content of the lumber will fall more rapidly, especially if it is in smaller pieces, to about 9 percent. Later, the completed article may be put into the finishing room where the temperature is 80°. This rise in temperature alone will lower the relative humidity of the shop air to 34 percent and the lumber will dry out to about 6 percent moisture. The finished product may then be stored in a room where the temperature is again 60° and the relative humidity 60 percent with the result that the wooden parts will take on moisture and swell. When the article later appears in the store, office, or home, it may again dry out, checks may form, and glue joints may open up. In general, changes in moisture with small change in relative humidity take place slowly, especially if the wood is coated on all sides with varnish, shellac, paint, or other protective coatings. Although such coatings do not prevent the absorption of moisture, they do retard it.

The moisture content which wood has at the time of manufacture should correspond approximately to the average it will eventually attain in use, or slightly less. The relative humidity of the air surrounding the article in use should, therefore, govern the extent to which lumber is dried. This is of particular importance to manufacturers of furniture, cabinets, and other wooden products in which shrinking and swelling must be reduced to a minimum. Wooden articles sent to the coastal regions of the south Atlantic, Gulf, and Pacific States where the outdoor relative humidity is comparatively high the greater part of the year (Table 2) and where buildings are heated during a small portion of the year only, should have a higher moisture content than similar wooden articles sent to the Rocky Mountain region or to the inland valleys of the Southwest, where the relative humidity is comparatively low.

Explanation of Humidity

Although it is generally understood that by humidity is meant the moisture in the air, it is believed that a more detailed explanation will be of value.

Absolute humidity means the actual amount of moisture present in the air in the form of vapor. This may be expressed in grains per cubic foot, or grams per cubic meter, or in any other suitable units.

The maximum amount of moisture air can hold in the form of vapor varies with the temperature, as follows:

Temperature ° F.	Number of grains of moisture per cubic foot when saturated
20	1.25
40	2.90
60	5.80
80	11.00
100	20.00
120	34.00
140	57.00
160	91.00
180	140.00
200	208.00
220	*302.00

*At 17.2 pounds absolute pressure.

In kiln drying, it is more convenient to express the amount of moisture in the air as a percentage of the moisture saturation at the temperature of the air. This is known as the relative humidity. For example, at 100° F. the air can hold 20 grains of moisture per cubic foot when fully saturated, but if only 5 grains are present, the air is one-fourth saturated, or has a relative humidity of 25 percent. On the other hand, a relative humidity of 25 percent at 160° means that 22.7 grains of moisture per cubic foot are present. When the air is fully saturated, the relative humidity is said to be 100 percent.

Since the amount of moisture that air can hold varies with the temperature, it follows that heating air containing any fixed quantity of vapor lowers its relative humidity, and, conversely, cooling air raises its relative humidity. When air has been cooled sufficiently to become fully saturated, it is said to be at the dew point. If its temperature is lowered still more, the air cannot hold all the moisture and condensation takes place.

The Relation of Relative Humidity to Evaporation

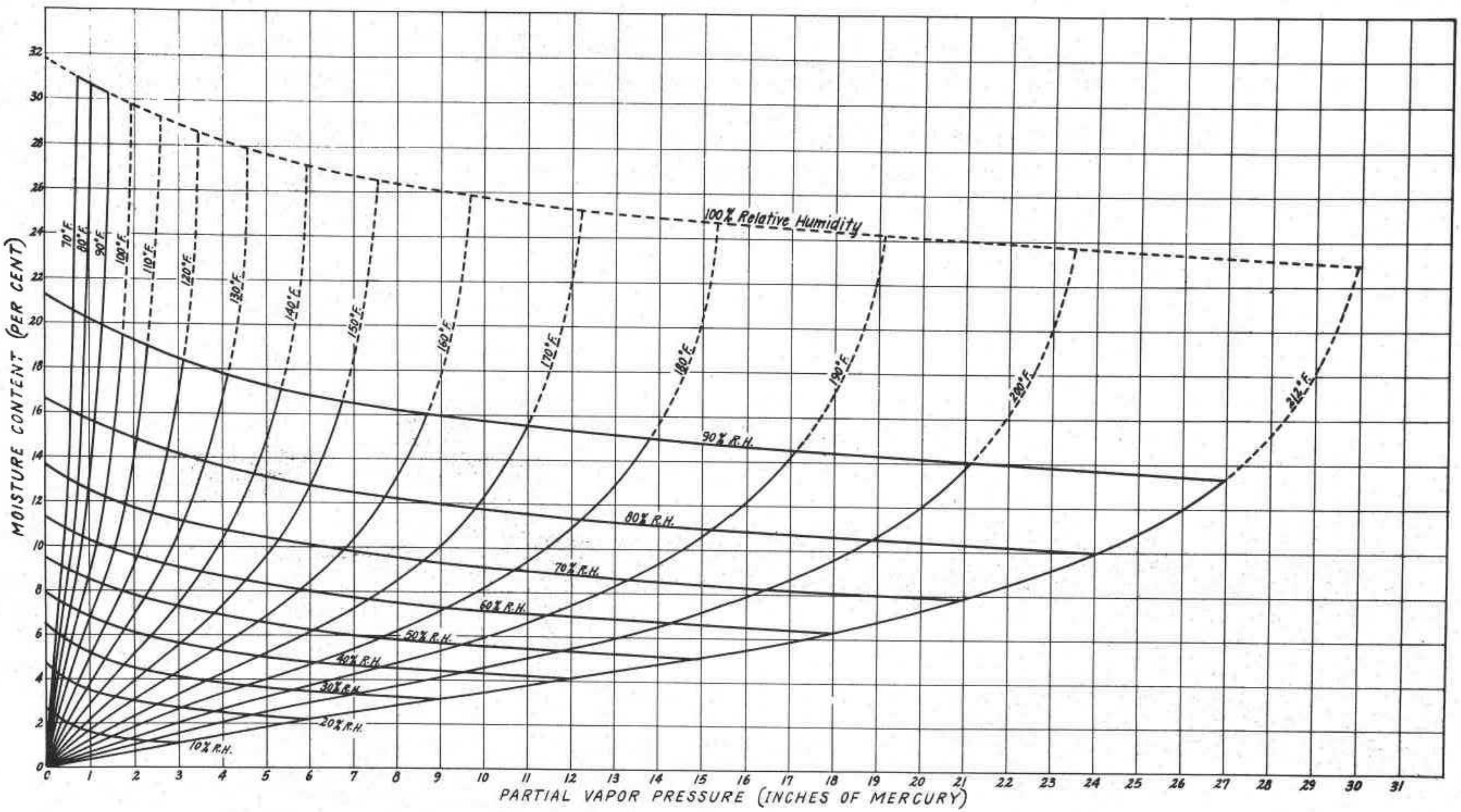
The average rate at which evaporation takes place from wet surfaces depends considerably on the relative humidity of the air. At 100 percent relative humidity evaporation ceases entirely. However, the average rate of evaporation is not altogether proportional to the relative humidity. For example, at a relative humidity of 60 percent and a temperature of 110°, the evaporation will take place at a certain rate, while at 60 percent relative humidity and 130° the rate will be much greater. The reason is that at the higher temperature the difference between the vapor pressure of the water in the wood and of the water vapor in the air is greater.

In drying lumber, however, we do not have very wet surfaces, or only for a very limited time, and therefore the average rate of drying in a kiln is only partially governed by its relative humidity. Another factor enters in; namely, the average rate at which the moisture comes to the surface of the wood. This average rate depends on the kind and thickness of lumber, whether plain-sawed or quarter-sawed, sapwood or heartwood, as well as on the atmospheric conditions. Heat hastens the transfusion of the moisture from the interior outward; therefore, the temperature should be kept as high as the lumber will stand, and the relative humidity should be regulated accordingly.

How to Determine Relative Humidity

Relative humidity in the dry kiln or in the atmosphere may be determined with a wet and dry-bulb hygrometer. A hygrometer is made by attaching two similar thermometers to a convenient stand, the bulb of one being kept moist by means of a wick which dips into a vessel of water. These instruments depend for their action on the fact that the drier the air, the more rapid will be the evaporation from a wet body exposed to the air. Since evaporation requires heat, it follows that the extent to which a wet body is cooled by evaporation will depend upon the ability of the surrounding air to absorb moisture. If the air is saturated, no evaporation takes place and the wet and dry-bulb thermometers read alike. If the air is not saturated, evaporation will take place and the cooling effect of evaporation will cause the wet bulb to indicate a lower temperature than the dry bulb. The dry bulb gives the actual temperature, regardless of the relative humidity

To determine relative humidity by means of a hygrometer requires a fair circulation of air. At ordinary temperatures a circulation of at least 15 feet per second is required, but at higher temperatures the rate may be lower. If the circulation is feeble it is necessary to fan the instrument before an accurate reading can be made. Read the temperatures and subtract the reading of the wet-bulb thermometer from that of the dry bulb thermometer. In the relative humidity table on the following page find the temperature of the dry bulb in the left-hand column and follow across the table to the column under "Difference Between Wet and Dry-Bulb Temperatures," as given at the top of the table. The figure given in the table at the intersection is the relative humidity, expressed in percentage. As an example, the following may be taken: Dry-bulb temperature, 140° F.; wet-bulb temperature, 132° F.; difference, 8° F. Find the dry-bulb temperature in the left-hand column, and follow across the table to the proper column under "Difference Between Wet and Dry-Bulb Temperature." At 8° F. difference, we find the figure 79, which is the relative humidity expressed in percentage.



THE MOISTURE CONTENT OF SITKA SPRUCE
AT EQUILIBRIUM WITH THE INDICATED TEMPERATURE, PARTIAL VAPOR PRESSURE,
AND RELATIVE HUMIDITY

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Figure 1

Relative humidity table for use with wet- and dry-bulb thermometers.

Temperature of dry bulb	Difference between wet-bulb and dry-bulb thermometers, in degrees Fahrenheit																																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1																														
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3																									
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3																				
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	11	9	7	5	3	1														
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	19	17	15	13	12	10	8	7	5	4	2	1								
102	96	93	90	86	83	80	77	74	71	68	65	62	60	57	55	52	49	47	45	42	40	38	36	34	32	30	28	26	24	22	20	18	16	15	13	11	10	8	7	5	4	2	1							
104	97	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	43	41	39	37	35	33	31	29	27	25	23	21	20	18	16	14	13	11	10	8	7	5	4	2	1						
106	97	93	90	87	84	81	78	75	72	69	66	64	61	58	56	53	51	49	46	44	42	40	38	36	34	32	30	28	26	24	23	21	19	17	16	14	13	11	10	8	7	5	4	3	1					
108	97	93	90	87	84	81	78	75	72	70	67	64	62	59	57	54	52	49	47	45	43	41	39	37	35	33	31	29	27	25	24	22	20	19	17	16	14	12	11	10	8	7	5	4	3	2				
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	25	23	21	20	18	17	15	14	12	11	10	8	7	6	4	3	2	1		
112	97	94	90	87	84	81	79	76	73	70	68	65	63	60	58	55	53	51	49	47	44	42	40	38	36	35	33	31	29	27	26	24	23	21	19	18	16	15	14	12	11	9	8	7	6	4	3	2	1	
114	97	94	91	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	49	47	45	43	41	39	37	35	34	32	30	28	27	25	24	22	20	19	18	16	15	13	12	11	9	8	7	6	5	3	2	1
116	97	94	91	88	85	82	79	76	74	71	69	66	64	61	59	57	54	52	50	48	46	44	42	40	38	36	34	33	31	29	28	26	25	23	22	20	19	17	16	14	13	12	11	9	8	7	6	5	4	2
118	97	94	91	88	85	82	79	77	74	72	69	67	64	62	59	57	55	53	51	49	47	45	43	41	39	37	35	34	32	30	29	27	25	24	23	21	20	18	17	16	14	13	12	11	9	8	7	6	5	4
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	29	28	26	25	23	22	21	19	18	17	15	14	13	12	10	9	8	7	6	5
122	97	94	91	88	85	83	80	77	75	72	70	67	65	63	60	58	56	54	52	50	48	46	44	42	40	39	37	35	34	32	30	29	27	26	24	23	22	20	19	18	16	15	14	13	11	10	9	8	7	6
124	97	94	91	88	85	83	80	78	75	73	70	68	65	63	61	59	57	54	52	50	48	47	45	43	41	39	38	36	34	33	31	30	28	27	25	24	22	21	20	18	17	16	15	14	12	11	10	9	8	7
126	97	94	91	88	86	83	80	78	75	73	70	68	66	64	61	59	57	55	53	51	49	47	45	44	42	40	38	37	35	33	32	30	29	27	26	25	23	22	21	19	18	17	16	15	13	12	11	10	9	8
128	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62	60	58	56	54	52	50	48	46	44	42	41	39	37	36	34	33	31	30	28	27	25	24	23	22	20	19	18	17	16	14	13	12	11	10	9
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	33	32	30	29	28	26	25	24	22	21	20	19	18	16	15	14	13	12	11	10
132	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63	61	58	56	55	53	51	49	47	45	44	42	40	39	37	36	34	33	31	30	28	27	26	24	23	22	21	20	18	17	16	15	14	13	12	11
134	97	94	92	89	86	84	81	79	76	74	72	69	67	65	63	61	59	57	55	53	51	49	48	46	44	43	41	39	38	36	35	33	32	30	29	28	26	25	24	23	21	20	19	18	17	16	15	14	13	12
136	97	94	92	89	86	84	81	79	77	74	72	70	68	65	63	61	59	57	55	54	52	50	48	46	45	43	41	40	38	37	35	34	33	31	30	28	27	26	25	23	22	21	20	19	18	17	16	15	14	13
138	97	94	92	89	87	84	82	79	77	75	72	70	68	66	64	62	60	58	56	54	52	50	49	47	45	44	42	40	39	37	36	35	33	32	30	29	28	27	25	24	23	22	21	20	19	17	16	15	14	14
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	37	35	34	32	31	30	29	27	26	25	24	23	21	20	19	18	17	16	15	14
142	97	95	92	89	87	84	82	80	77	75	73	70	68	66	64	62	60	58	57	55	53	51	49	48	46	44	43	42	40	39	37	36	34	33	32	30	29	28	27	26	24	23	22	21	20	19	18	17	16	15
144	97	95	92	89	87	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55	53	52	50	48	47	45	44	42	41	39	38	36	35	34	32	31	30	29	27	26	25	24	23	22	21	20	19	18	17	16
146	97	95	92	90	87	85	82	80	78	75	73	71	69	67	65	63	61	59	57	56	54	52	50	49	47	45	44	43	41	40	38	37	36	35	33	32	30	29	28	27	26	25	24	22	21	20	19	18	17	17
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152	98	95	93	90	88	85	83	81	79	76	74	72	70	68	66	64	62	60	59	57	55	53	52	50	48	47	46	44	42	41	40	39	37	36	35	33	32	31	30	29	28	26	25	24	23	22	21	20	19	19
154	98	95	93	90	88	85	83	81	79	77	74	72	70	68	66	65	63	61	59	57	56	54	52	50	49	47	46	44	43	42	40	39	38	37	35	34	33	32	30	29	28	27	26	25	24	23	22	21	20	19
156	98	95	93	90	88	85	83	81	79	77	74	72	71	69	67	65	63	61	59	58	56	54	53	51	49	48	46	45	43	42	41	40	38	37	36	34	33	32	31	30	29	28	27	25	24	23	23	22	21	20
158	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	63	61	60	58	56	55	53	51	50	48	47	45	44	43	41	40	39	38	36	35	34	33	31	30	29	28	27	26	25	24	23	22	21	20
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	42	41	39	38	37	35	34	33	32	31	30	29	28	27	25	24	24	23	22	21
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164	98	95	93	91	88	86	84	82	80	78	75	73	72	70	68	66	64	62	61	59	58	56	54	52	51	49	48	47	45	44	43	41	40	39	38	36	35	34	33	32	31	30	29	28	26	25	25	24	23	22
166	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	66	65	63	61	59	58	56	54	53	51	50	48	47	45	44	43	42	41	39	38	37	36	35	33	32	31	30	29	28	27	26	25	24	23	23
168	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	67	65	63	61	60	58	56	55	53	52	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	44	43	41	40	39	38	37	35	34	33	32	31	30	29	28	27	26	25	24	24
172	98	95	93	91	89	86	84	82	81	78	76	74	73	71	69	67	66	64	62	60	59	57	55	54	53	51	50	48	47	46	45	43	42	41	39	38	37	36	35	34	33	32	31	30	28	27	26	26	25	24
174	98	95	93	91	89	87	84	83	81	78	76	75	73	71	69	67	66	64	62	61	59	57	56	54	53	51	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28	27	26	25	24
176	98	96	94	91	89	87	85	83	81	79	77	75	73	71	70	68	66	64	63	61	60	58	56	55	53	52	50	49	48	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31	29	28	27	27	26	25
178	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	66	64	63	61	60	58	56	55	54	52	51	49	48	47	46	44	43	42	41	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	46	45	43	42	41	40	39	38	36	35	35	34	33	31	30	29	28	27	27	26
182	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	67	65	63	62	60	59	57	56	54	53	51	50	49	48	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26
184	98	96	94	92	89	87	85	83	82	79	77	76	74	72	70	69	67	65	64	62	61	59	57	56	55	53	52	50	49	48	47	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	29	28	27	27
186	98	96	94	92	90	87	85	83	82	80	78	76	74	72	71	69	67	66	64	62	61	59	58	56	55	53	52	51	49	48	47	45	44	43	42	41	40	39	38	37	36	35	34	33	32	30	30	29	27	27
188	98	96	94	92	90	87	85	84	82	80	78	76	74	73	71	69	68	66	64	63	62	59	58	57	55	54	52	51	50	49	47	46	45	44	43	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	48	46	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	30	29	28
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	49	48	47	46	45	43	42	41	40	39	38	37	36	35	34	33	32	32	31	30
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	65	64	63	61	60	59	57	56	54	53	52	51	50	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	32
220	98[a]	96[a]	94[a]	92[a]	91[a]	89[a]	87[a]	85[b]	83	82	80	78	77	75	74	72	71	69	68	66	65	64	62	61	60	58	57	56	54	53	52	51	50	48	47	46	45	44	43	42	41	41	39	39	38	37	36	35	34	33

[a]Possible only at pressures higher than normal atmosphere.

[b]Superheated steam, at normal atmospheric pressure, no air present. At lower humidities air is mixed with the water vapor.