Lecture 10 : properties of pure substance

by: Asst. lect. Karrar Al-Mansoori

10) Properties of Pure Substances

Properties and the behavior of substances are very important for our studies of devices and thermodynamic systems. The steam power plant and the nuclear propulsion system have very similar processes, using water as the working substance. Water vapor (steam) is made by boiling at high pressure in the steam generator followed by expansion in the turbine to a lower pressure, cooling in the condenser, and a return to the boiler by a pump that raises the pressure.

We must know the properties of water to properly size equipment such as the burners or heat exchangers, turbine, and pump for the desired transfer of energy and the flow of water.

❖ **ما هي المادة ؟ ولماذا يجب علينا دراسة خصائص المواد ؟**

- **المادة : هي كل شيء له كتلة ، ويشغل حيزا ، ونحس به ، وتختلف عن بعضها البعض بأختلاف خصائصها وصفاتها .**
- **خواص المادة هي سمات مميزة لكل مادة، وتُعرف بأنها غير مقدارية (لا تختلف باختلاف مقدار المادة) مثل الخصائص الكهربائية والحرارية وغيرها .**

في محطات توليد الطاقة مثلا يُستخدم الماء كمادة أساسية في دورة التوليد لذا وجب علينا معرفة خصائص ومكونات وحالات الماء لمعرفة كيفية التعامل مع هذه المادة والاستفادة منها بالشكل الأمثل وكذلك معرفة اختيار حجم المعدات مثل المبادلات الحرارية والتوربينات والمضخات بالشكل الصحيح لنقل الطاقة المطلوبة وتدفق المياه.

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10-1 Pure Substance

A substance that has a fixed chemical composition throughout is called a pure substance. A pure substance does not have to be of a single chemical element or compound, however. A mixture of various chemical elements or compounds also qualifies as a pure substance as long as the mixture is homogeneous. A substance that has a fixed chemical composition throughout is called a pure substance. Water, nitrogen, helium, and carbon dioxide, for example, are all pure substances.

- Air, for example, is a mixture of several gases, but it is often considered to be a pure substance because it has a uniform chemical composition (Fig. 10–1). However, a mixture of oil and water is not a pure substance. Since oil is not soluble in water, it will collect on top of the water, forming two chemically dissimilar regions.

- A mixture of two or more phases of a pure substance is still a pure substance as long as the chemical composition of all phases is the same (Fig. 10 –2). ***A mixture of ice and liquid water***, for example, is a pure substance because both phases have the same chemical composition. ***A mixture of liquid air and gaseous air***, however, is not a pure substance since the composition of liquid air is different from the composition of gaseous air, and thus the mixture is no longer chemically homogeneous.

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❖ ما هي المواد النقية ؟

- هي أي مادة لها تركيب كيميائي ثابت ومتجانس مثل غاز النيتروجين او الهيليوم او الماء الخ .
- المواد النقية اما ان تكون عنصر واحد فقط او ان تكون خليط من اكثر من مادة لكن يجب ان يكون هناك تجانس تام بينهم مثل الهواء ، لكن خليط الماء والزيت غير متجانس لذا فهو ليس **pure substance** .
- ان وجود نفس المادة في حالتين مختلفتين معا في نفس الوقت تعتبر **pure** أيضا وذلك لان تركيبها الكيميائي يبقى ثابتا مثل الثلج والماء معا او الماء عندما يكون في الحالتين السائلة والغازية معا فهما بنفس التركيب الكيميائي H_2O .

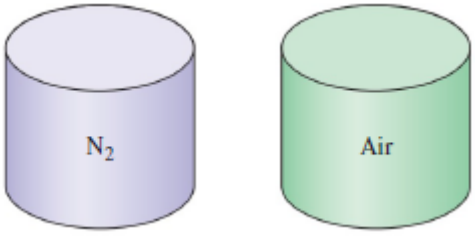

Figure (10-1): Nitrogen and gaseous air are pure substances.

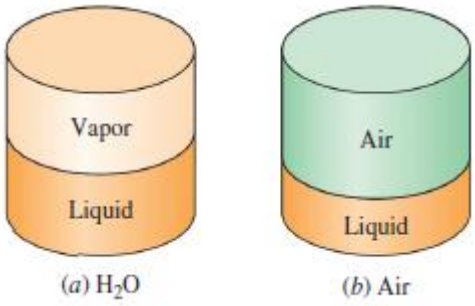

Figure (10-2): A mixture of liquid and gaseous water is a pure substance, but a mixture of liquid and gaseous air is not.

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10-2 Phase-Change Processes of Pure Substances

We all know from experience that substances exist in different phases. At room temperature and pressure, copper is a solid, mercury is a liquid, and nitrogen is a gas. Under different conditions, each may appear in a different phase. Even though there are three principal phases—solid, liquid, and gas. A substance may have several phases within a principal phase, each with a different molecular structure. Carbon, for example, may exist as graphite or diamond in the solid phase. Helium has two liquid phases; iron has three solid phases.

There are many practical situations where two phases of a pure substance coexist in equilibrium. Water exists as a mixture of liquid and vapor in the boiler and the condenser of a steam power plant. The refrigerant turns from liquid to vapor in the freezer of a refrigerator.

❖ اطوار المادة وحالاتها:

- كل مادة تتواجد في الطبيعة بطور معين عند الظروف الطبيعية ، فمثلا عند درجة حرارة وضغط الغرفة الاعتياديين يكون النحاس بالحالة الصلبة والزئبق كسائل والنيتروجين كغاز ، لكن سرعان ما تتغير طبيعة المادة عند تعريضها لضروف معينة من ضغط ودرجة حرارة .
- ممكن ان تكون المادة على اشكال معينة في الطور الواحد ، فمثلا يتواجد الكاربون بهيئة جرافيت او الماس في الطور الطلب للمادة

➢ ***10.2.3 Solid Phase:*** [1] Atoms or molecules have all three types of motion, vibration, rotation and translation but they are very close together. As a result, they cannot travel far at all before they collide. [2] Each molecule moves about within a small space and does not tend to wander.

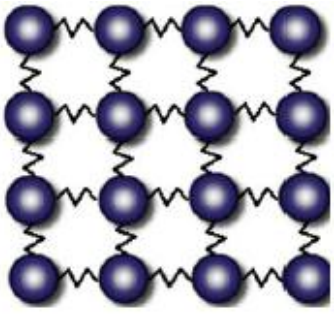

Figure (10-3): Solid Phase

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- ***10.2.2 Liquid Phase:*** [1] is not much different from that of the solid phase, except the molecules are no longer at fixed positions relative to each other and they can rotate and translate freely. [2] In a liquid, the intermolecular forces are weaker relative to solids, but still relatively strong compared with gases.

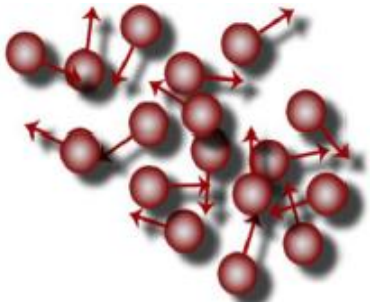

Figure (10-4): Liquid Phase

- ***10.2.1 Gas Phase:*** [1] Molecules move randomly with three different types of motion: vibration, rotation and translation. [2] Molecules are separated by large distances and travel a long way between collisions.

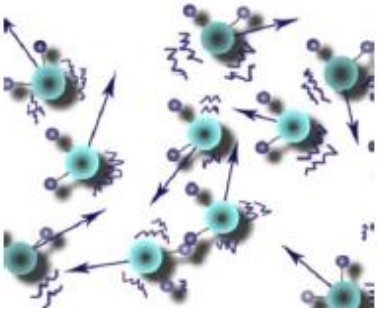

Figure (10-5): Gas Phase

مقارنة بين حالات المادة الثلاثة :

الطور الصلب	الطور السائل	الطور الغازي
قوة التجاذب بين الجزيئات تكون كبيرة جدا لذا فالجزيئات تكون قريبة من بعضها البعض ودائما تتحرك الجزيئات حول مكانها	قوة التجاذب بين الجزيئات اقل مما في الحالة الصلبة وتنتقل بحرية اكبر.	القوى بين الجزيئات تكون ضعيفة جدا وحركتها عشوائية والمسافة بين الجزيئات كبيرة وهي الحالة الأكثر طاقة

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10-3 Compressed Liquid and Saturated Liquid

Consider a piston–cylinder device containing liquid water at 20°C and 1 atm pressure (state 1, Fig. 10–6). *Under these conditions, water exists in the liquid phase, and it is called a compressed liquid, or a subcooled liquid,* meaning that it is not about to vaporize. Heat is now transferred to the water until its temperature rises to, say, 40°C. As the temperature rises, the liquid water expands slightly, and so its specific volume increases. To accommodate this expansion, the piston moves up slightly. The pressure in the cylinder remains constant at 1 atm during this process since it depends on the outside barometric pressure and the weight of the piston, both of which are constant. Water is still a compressed liquid at this state since it has not started to vaporize. As more heat is transferred, the temperature keeps rising until it reaches 100°C (state 2, Fig. 10–7). *At this point water is still a liquid, but any heat addition will cause some of the liquid to vaporize. That is, a phase-change process from liquid to vapor is about to take place. A liquid that is about to vaporize is called a saturated liquid.* Therefore, state 2 is a saturated liquid state.

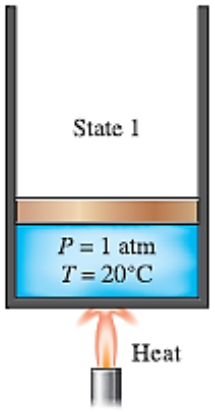

Figure (10-6): At 1 atm and 20°C, water exists in the liquid phase (*compressed liquid*).

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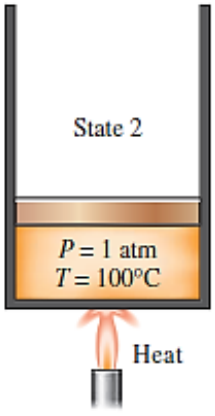

Figure (10-7): At 1 atm pressure and 100°C, water exists as a liquid that is ready to vaporize (*saturated liquid*).

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10-4 Saturated Vapor and Superheated Vapor

Once boiling starts, the temperature stops rising until the liquid is completely vaporized. That is, the temperature will remain constant during the entire phase-change

بمجرد بدء الغليان ، تتوقف درجة الحرارة عن الارتفاع حتى يتم تبخير السائل تمامًا .أي أن درجة الحرارة ستبقى ثابتة أثناء عملية تغيير الطور بالكامل إذا كان الضغط ثابتًا.

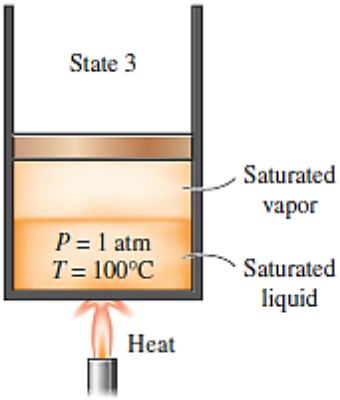

Figure (10-8): As more heat is transferred, part of the saturated liquid vaporizes (*saturated liquid–vapor mixture*).

This can easily be verified by placing a thermometer into boiling pure water on top of a stove. At sea level ($P = 1_{atm}$), the thermometer will always read 100°C if the pan is uncovered or covered with a light lid. *During a boiling process، the only change we will observe is a large increase in the volume and a steady decline in the liquid level as a result of more liquid turning to vapor .*

خلال عملية الغليان هذه ، التغيير الوحيد الذي سنلاحظه هو زيادة كبيرة في الحجم وانخفاض مستمر في مستوى السائل نتيجة تحول أكثر السائل إلى بخار.

- Midway about the vaporization line (state 3, Fig. 10–8), the cylinder contains equal amounts of liquid and vapor. As we continue transferring heat, the vaporization process continues until the last drop of liquid is vaporized (state 4 ، Fig. 10-9).

في لحظة معينة – اثناء إضافة الحرارة _ نلاحظ بان الأسطوانة تحتوي على كميات متساوية من السائل والبخار(الحالة ٣) .بينما نستمر في اضافة الحرارة ، تستمر عملية التبخير حتى تتبخر آخر قطرة من السائل (الحالة ٤) .

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- When all liquid is vaporized (state 4 ، Fig. 10-9) the entire cylinder is filled with vapor that is on the borderline of the liquid phase. Any heat loss from this vapor will cause some of the vapor to condense (phase change from vapor to liquid). *A vapor that is about to condense is called a saturated vapor.* Therefore, state 4 is a saturated vapor state. *A substance at states between 2 and 4 is referred to as a saturated liquid–vapor mixture* since the liquid and vapor phases coexist in equilibrium at these states.

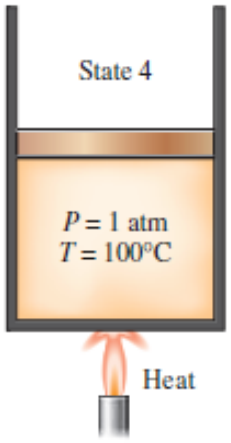

Figure (10-9): At 1 atm pressure, the temperature remains constant at 100°C until the last drop of liquid is vaporized (*saturated vapor*).

عندما يتم تبخير جميع السائل تمتلئ الأسطوانة بأكملها بالبخار الموجود على الخط الحدودي للطور السائل . لذا فأن أي فقدان للحرارة من هذا البخار ستسبب في تكثف بعض البخار (تغير الطور من بخار إلى سائل .(يسمى البخار الذي على وشك التكاثف بخار مشبع) .

One the phase-change process is completed, we are back to a single phase region again (this time vapor), and further transfer of heat results in an increase in both the temperature and the specific volume (Fig. 10-10). At state 5, the temperature of the vapor is, let us say, 300°C; and if we transfer some heat from the vapor, the temperature may drop somewhat but no condensation will take place as long as the temperature remains above 100 °C for (P =1 atm).

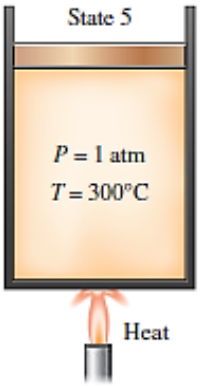

Figure (10-10): As more heat is transferred, the temperature of the vapor starts to rise (*superheated vapor*).

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A vapor that is not about to condense (i.e., not a saturated vapor) is called a superheated vapor. Therefore, water at state 5 is ***a superheated vapor.*** This constant-pressure phase-change process is illustrated on a T-v diagram in Fig. (10-11). If the entire process described here is reversed by cooling the water while maintaining the pressure at the same value, the water will go back to state 1، retracing the same path, and in so doing, the amount of heat released will exactly match the amount of heat added during the heating process. In our daily life, water implies liquid water and steam implies water vapor. ***In thermodynamics, however, both water and steam usually mean only one thing: H_2O.***

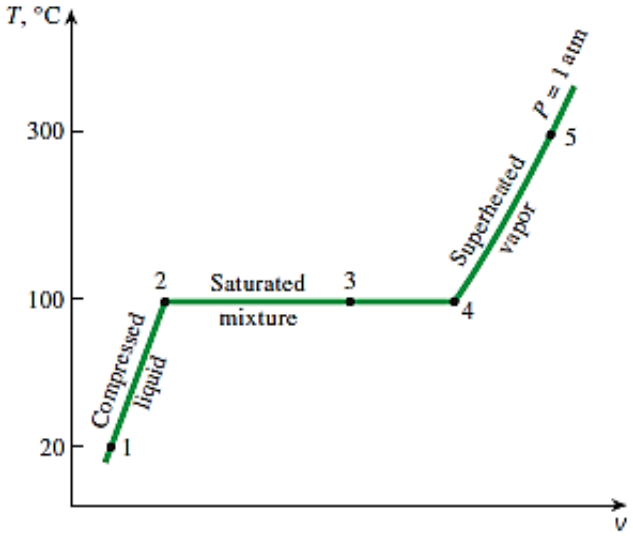

Figure (10-11): *T-v* diagram for the heating process of water at constant pressure.

- يسمى البخار الذي لا يتكثف ببخار فائق السخونة او بخار محمص. لذلك فأن الماء الموضح في (الحالة ٥) هو بخار محمص .
- إذا تم عكس العملية بالكامل كما كوضحة في الشكل أعلاه على مخطط الطور عن طريق تبريد المياه مع الحفاظ على الضغط بنفس القيمة ، فإن الماء سيعود إلى الحالة ١ وبهذا ، فإن كمية الحرارة الصادرة سوف تتطابق تمامًا مع كمية الحرارة المضافة أثناء عملية التسخين .