THE LESA MIXED STEAM POWER PLANT
EFFICIENCY CALCULATION

A Refutation of the Second Main Theorem of Thermodynamics

Calculation of a Rankine Cycle Process with the Mixture of Water and Benzene

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CONTENTS

EFFICIENCY CALCULATION OF A RANKINE CYCLE PROCESS WITH THE MIXTURE OF WATER AND BENZENE

1 SUMMARY:

The efficiency for a Rankine cycle process is calculated which is run with a mixture of water and benzene steam as the working medium. This calculation shows that the efficiency in such a case is significantly above Carnot efficiency. This proves that the 2nd main theorem of thermodynamics can be overcome by changing the substance properties of the working medium in a cycle process.

2 INTRODUCTION

This line of argumentation exclusively uses known equations, calculation methods and table values which are today customary in thermodynamics. As a known experimental fact, it is presumed that water and benzene segregate in the liquid phase and that two liquid levels are formed.

The example calculation carried out here assumes a boiler temperature of 450 K and a condenser temperature of 350 K. Similar results can be achieved with any other temperatures below the critical temperature of benzene (562.6 K).

3   GIBB'S PHASE RULE

Gibb's phase rule is initially applied to the water/benzene mixture.

$$k + 2 = n + \sigma \qquad (1)$$

where:

k – number of components

n – number of phases

σ – number of degrees of freedom

2 components + 2 = 3 phases + 1 degree of freedom

3 phases exist when a water and benzene mixture evaporates, i.e. two liquid phases – water, benzene – and one steam phase – mixed steam. Only one degree of freedom remains which is determined by the temperature which the system has. This means that the pressure and the concentration of the mixed steam are also determined. The mixed steam hence follows each temperature with a special pressure and a special concentration. When the temperature changes, part of a component must precipitate as mist, or the other component must additionally evaporate until the correct concentration develops.

4   THE AZEOTROPIC POINT

The triplet made up of temperature, pressure and concentration is also called the azeotropic point. When the sum of all azeotropic points is plotted in a T-x diagram (Fig. 1) this then results in an azeotropic line.

Since 3 phases belong to each azeotropic point, the line which connects all azeotropic points is also called a three-phase line. With rising temperature, the three-phase line for the water and benzene mixture is inclined towards the water side in the T-x diagram. This means that the share of water in the mixed steam increases with rising temperature and drops with falling temperature.
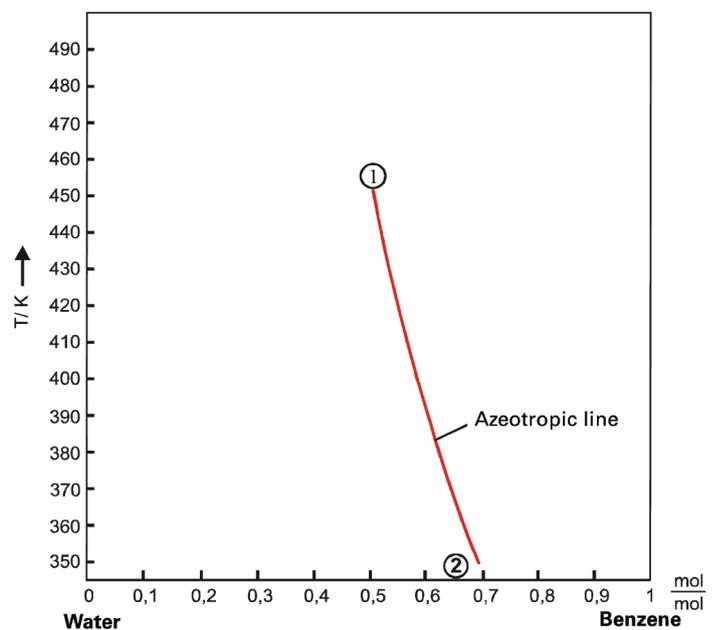
[Fig. 1]

5 THE ADIABATIC RELAXATION OF SINGLE SUBSTANCES

When the steam of a single substance undergoes adiabatic relaxation in the wet-steam region, this then extends exactly along the steam pressure curve. The increase in volume is determined by the piston movement. Pressure and temperature follow, directly linked via the steam pressure curve. The condition dS = 0 is fulfilled at all times which means that the entropy does not change. Nothing other than this has ever been observed with single substances.

## 6 THE ADIABATIC RELAXATION OF THE WATER/BENZENE MIXTURE

The adiabatic relaxation of a two-substance mixture also proceeds along the steam pressure curve. This is, however, also the azeotropic line where the concentration occurs as an additional parameter. The increase in volume resulting from the movement of the piston is followed not just by the pressure and temperature, but also by the steam composition. As a precondition for the steam concentration to be able to follow the azeotropic line, a significant amount of water must precipitate as mist from the mixed steam when the temperature drops.

This is a constraint condition which the mixed steam must follow. The question is hence whether the second constraint condition, i.e. the constancy of entropy, can be fulfilled? The final result presented in this study is only plausible if an entropy decrease is assumed. If entropy is understood according to Boltzmann as the measure of order of a system, the course of the azeotropic line imposes a very strict order condition upon the mixed steam. This means that the degree of order increases and the entropy decreases.

This order condition does not exist in the case of single substances because concentration as a parameter does not occur there. It is hence not surprising that two-substance mixtures as the working medium open up possibilities which cannot exist with single substances.

7 THE RANKINE CYCLE PROCESS

Due to the direct link between pressure and temperature, the evaporation of the water/benzene mixture of substances proceeds as an isothermal/isobaric process like in the case of single substances. The Rankine cycle process without superheating hence presents itself for our system in the very same manner as for all single substances.
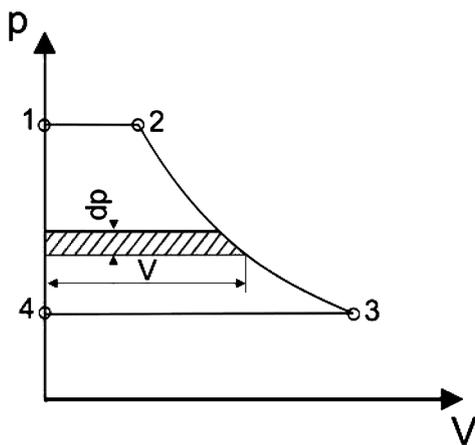
[Fig. 2]

8 CLAPEYRON'S EQUATION

Due to the isothermal-isobaric process, Clapeyron's equation can be used to determine the evaporation and/or condensation heat.

$$r = \frac{dp}{dT} \cdot (v'' - v') \cdot T \qquad (2)$$

where:

r – evaporation heat

$\frac{dp}{dT}$ – gradient of the steam

v'' – steam volume

v' – liquid volume

T – temperature

If the enthalpy in point (4) in Fig. 2 is arbitrarily set at 0, the following values are obtained for the evaporation heat:

from (1) to (2) $r_{450K} = 614.5 \, \frac{kJ}{kg}$ refer to Appendix A

from (3) to (4) $r_{350K} = 527.9 \, \frac{kJ}{kg}$ refer to Appendix B

with (1) liquid pre-heating $= 247.4 \, \frac{kJ}{kg}$ refer to Appendix C

9 EFFICIENCY CALCULATION

With $h_4 = 0$ the following equation applies:

$$Q_{zu} = h_2 = r_{450} + liquid\,pre\text{-}heat. = 614.5\,\frac{kJ}{kg} + 247.4\,\frac{kJ}{kg} = 861.9\frac{kJ}{kg}$$

Neglecting the liquid volume (the pump delivery rate of the feeding-water pump), the following equation applies:

$$Work\ output\ = \int vdp = h_2 - h_3 \qquad (3)$$

The efficiency of the Rankine process with the water/benzene mixture as the working medium is hence calculated as follows:

$$\eta = \frac{\int vdp}{Q_{zu}} = \frac{h_2 - h_3}{h_2} = \frac{862\frac{kJ}{kg} - 528\,\frac{kJ}{kg}}{862\,\frac{kJ}{kg}} = \frac{334}{862} = 38.7\%$$

Compare this to the efficiency according to Carnot:

$$\eta_{Carnot} = \frac{T_1 - T_2}{T_1} = \frac{450K - 350K}{450K} = 22.2\% \qquad (4)$$

If one were to additionally consider that the liquid pre-heating process is not an isothermal process, the Carnot value would even have to be adjusted downwards.

This result shows that Carnot efficiency can be surpassed by cycle processes in which mixed steams are used as the working medium.

10 HISTORY

Hungarian engineer Arnold Irinyi was the first to describe this phenomenon in 1931. He conducted several tests in Hamburg, running conventional steam engines on mixed steam. In all cases, he was able to achieve efficiencies that were significantly higher than in pure water steam mode. Several independent engineers confirmed his results. However, this technology did not prevail and is today largely unknown.

Marinebaurat (Senior Marine Engineer) Rudolph Meyer reported as follows on his measurements: [1]

... This fact clearly exists!

I am fully aware of the fact that it is very surprising to every one of us and that critical technicians and sober scientists must consider it as almost unbelievable in view of what has so far been considered to be at most achievable.

I and all the gentlemen involved in the tests and their evaluation felt the same because others too carried out tests with the same result. ...

... Apart from minor, insignificant variations of individual values, the result always remained the same throughout, so that the practical success of the Irinyi process is now a proven fact for me – and I may say also for the gentlemen who repeat these tests any number of times – and must be a new empirical fact firmly established in science ...

11 THE LESA MIXED STEAM ENGINE

The Rankine cycle process described herein is not used for the development of the LESA mixed steam engine. It was selected for the purposes of this explanation solely because of the simple way in which it can be presented.

The LESA mixed steam engine achieves efficiency rates of 60% to 65% within the temperature range described here. The dual process developed by Dr. Rudolph Doczekal is used for this purpose.

The dual process is based on the Irinyi cycle process, but takes this a number of crucial steps further. It is much more complex and requires readers to have a much more profound knowledge of thermodynamics.

A functional model of the future LESA mixed steam engine with a power of around 200 W very clearly demonstrates the efficiency increasing effect of the addition of benzene to the water steam.

12 CONCLUSION

The most important statement of the 2nd main theorem of thermodynamics is that it is impossible to build a perpetuum mobile of the second type. This indirectly means that nature never provides us with substances which have properties that enable the implementation of such a machine. The 2nd main theorem is hence a material theory which described substance properties which are permitted and substances properties which are not permitted.

This material theory has so far been confirmed time and again by the manifold knowledge of the properties of substances. This also means that the 2nd main theorem can only be refuted with concrete substance properties. This has taken place here.

It is startling and frightening to confess that a firmly established law of physics now stands on shaky ground. In the past, it was considered to be the best-proven natural law and it is hard to accept the idea that this law can be overcome.

But if we accept this unpleasant fact and face the importance, possibilities unforeseeable today and fortune will open up and enable us to re-shape many aspects of our lives. Let us tackle this enormous task in order to give our children a world worth living in.

13 APPENDIX

APPENDIX A:
CALCULATION OF THE EVAPORATION HEAT OF THE MIXED STEAM AT 450 K

As shown above, evaporation takes place as an isothermal/isobaric process. Clapeyron's equation can hence be used to calculate the evaporation heat.

$$r_{450} = \left(\frac{dp}{dT} \right) \cdot \left(v'' - v' \right) \cdot 450K \qquad (5)$$

A.1 DETERMINING THE GRADIENT OF THE STEAM PRESSURE CURVE AT 450 K

In order to determine $\frac{dp}{dT}$ the steam pressure must be determined first. In this special case, Dalton's law is applicable according to which the partial pressures add up to form the total pressure.

$$p_{total} = p_{water} + p_{benzene} \qquad (6)$$

Since it cannot be readily assumed that the steam phase still features an ideal behaviour at a pressure of around 19 bar, we subjected the course of the steam pressure curve to experimental verification and found that the above equation was confirmed with a deviation of less than 2%. Refer also to [3] Lüdecke and Lüdecke, page 654.

Equation (6) leads to:

$$\left(\frac{dp}{dT} \right)_{total} = \left(\frac{dp}{dT} \right)_{water} + \left(\frac{dp}{dT} \right)_{benzene} \qquad (7)$$

The gradients of the individual steam pressure curves of water and benzene at 450 K must hence be determined. Equation 5 can be transposed for this purpose.

$$\left(\frac{dp}{dT} \right)_{water} = \frac{r_{water}}{(v'' - v') \cdot 450K} \qquad (8)$$

Using the table values for water at 450 K, i.e.

evaporation heat: $\quad r = 2026 \ \frac{kJ}{kg}$

steam volume: $\quad v'' = 0.2078 \ \frac{m^3}{kg}$

liquid volume: $\quad v' = 0.0011 \ \frac{m^3}{kg}$

the following is obtained according to equation (8):

$$\left(\frac{dp}{dT}\right)_{water} = \frac{2026 \frac{kJ}{kg}}{(0.2078 - 0.0011) \frac{m^3}{kg} \cdot 450K} = 21.7814 \frac{kPa}{K}$$

Using the table values for benzene at 450 K, i.e.

evaporation heat: $r = 320.4 \frac{kJ}{kg}$

steam volume: $v'' = 0.04247 \frac{m^3}{kg}$

liquid volume: $v' = 0.00143 \frac{m^3}{kg}$

the following is obtained according to equation (8):

$$\left(\frac{dp}{dT}\right)_{benzene} = \frac{320.4 \frac{kJ}{kg}}{(0.04247 - 0.00143) \frac{m^3}{kg} \cdot 450K} = 17.3489 \frac{kPa}{K}$$

If these two results are put in equation (7), intermediate result A1 is obtained.

$$\left(\frac{dp}{dT}\right)_{total} = 21.7814 + 17.3489 = 39.13 \frac{kPa}{K}$$

INTERMEDIATE RESULT **A.1**: $\left(\frac{dp}{dT}\right)_{total} = 39.13 \frac{kPa}{K}$

A.2 DETERMINING THE STEAM VOLUME A 450 K

In order to determine the steam volume v" at 450 K, the steam composition must be determined beforehand. According to Avogadro's law, the following equation is derived for mole fraction x.

$$x_{water} = \frac{P_{water}}{P_{total}} \tag{9}$$

$$x_{benzene} = \frac{P_{benzene}}{P_{total}} \tag{9a}$$

When the table values for the steam pressures at 450 K i.e.

$water \; p = 9.315 \; bar$

$benzene \; p = 9.746 \; bar$

are put into equation (6), the steam pressure of the mixed steam is obtained.

$$p_{total} = 9.315 + 9.746 = 19.061 \; bar$$

Equations (9) and (9a) supply the mole fractions of the individual components.

$$x_{water} = \frac{9.315 \; bar}{19.061 \; bar} = 0.4887 \frac{mol}{mol}$$

$$x_{benzene} = \frac{9.746 \; bar}{19.061 \; bar} = 0.5113 \frac{mol}{mol}$$

These mole fractions must be converted to the weight fractions (w) according to equation 10 in order to be comparable with the other kilogramme values. With the molar weights of:

$water = 18 \frac{g}{mol}$

$benzene = 78 \frac{g}{mol}$

the following is obtained for the conversion:

ergibt sich für die Umrechnung:

$$w_{Wasser} = \cfrac{1}{\cfrac{1}{\cfrac{78}{18}\left(\cfrac{1}{x_{Water}}-1\right)}+1} \qquad (10)$$

$$x_{water} = 0.4887 \ \frac{mol}{mol} \qquad w_{water} = 0.1807 \ \frac{kgWater}{kgSteam}$$

$$w_{water} + w_{benzene} = 1 \qquad w_{benzene} = 0.8193 \ \frac{kgBenzene}{kgSteam}$$

One kilogramme of steam hence consists of 0.181 kg of water steam and 0.819 kg of benzene steam.

The experimental verification of the steam composition showed a satisfactory conformity with these calculated results. [2]

The volume of one kilogramme of mixed steam can be determined hereby.

The table values for the steam volumes, i.e.:

$$v''_{water} = 0.2078 \ \frac{m^3}{kg}$$

$$v''_{benzene} = 0.04247 \ \frac{m^3}{kg}$$

must be multiplied by the respective weight shares in the steam.

Steam volume of water:

$$0.2078 \ \frac{m^3}{kg} \cdot 0.181 \ \frac{kg}{kgSteam} = 0.0378 \ \frac{m^3}{kgSteam}$$

Steam volume of benzene:

$$0.04247 \ \frac{m^3}{kg} \cdot 0.819 \ \frac{kg}{kgSteam} = 0.0348 \ \frac{m^3}{kgSteam}$$

These two values should be identical because the respective steam shares are contained in the same volume. The difference of around 8% between these values is due to the fact that steams rather than ideal gases are present in this case. However, this difference has only a minor influence on the real final result. The mean value of the two results will be used in the further calculations.

$$v'' = 0.0363 \ \frac{m^3}{kgSteam}$$

INTERMEDIATE RESULT **A.2:** $\quad v'' = 0.0363 \ \dfrac{m^3}{kgSteam}$

An alternative approach:

DETERMINING THE STEAM VOLUME VIA THE SPECIFIC VOLUME OF THE INDIVIDUAL COMPONENTS.

At a first glance, it seems to be easier to calculate the volume and the composition of the mixed steam from the specific volumes of the individual components. According to Dalton, the following relationship is applicable to this:

$$v''_{mixed\ steam} = v''_{water} \cdot M_{water} = v''_{benzene} \cdot M_{benzene}$$
(11)

With the table value of:

$$v''_{water} = 0.2078 \ \frac{m^3}{kg}$$

$$v''_{benzene} = 0.04247 \ \frac{m^3}{kg}$$

put into equation 11, one obtains:

$$\frac{M_{water}}{M_{benzene}} = \frac{v''_{benzene}}{v''_{water}} = \frac{0.04247 \ \frac{m^3}{kg}}{0.2078 \ \frac{m^3}{kg}} = \frac{W_{water}}{W_{benzene}} = 0.2044 \ \frac{kg}{kg}$$

and $w_{water} + w_{benzene} = 1$ gives

$$w_{water} = 0.1697$$

$$w_{benzene} = 0.8303$$

The steam volume is hence according to (11):

$$v"_{water} = 0.2078 \frac{m^3}{kg} \cdot 0.1697 \frac{kg}{kgSteam} = 0.03526 \frac{m^3}{kgSteam}$$

$$v"_{benzene} = 0.04247 \frac{m^3}{kg} \cdot 0.8303 \frac{kg}{kgSteam} = 0.03526 \frac{m^3}{kgSteam}$$

With this calculation approach, the two volumes are of course absolutely identical which is necessarily the case from a purely mathematical point of view. However, the steam composition values determined with this calculation approach deviate more from our experimentally determined values than the values calculated in section A.2.

Furthermore, the value for the steam volume, i.e. $0.03526 \frac{m^3}{kgSteam}$ which is found here lies between the two values calculated under A.2.

$0.0378 \frac{m^3}{kgSteam}$ and $0.0348 \frac{m^3}{kgSteam}$.

This conformity demonstrates the reliability of the result obtained.

A.3 DETERMINING THE LIQUID VOLUME V' AT 450 K

The liquid volume results from the table values of the two liquids at 450 K, multiplied by the liquid volumes from which the steam is produced during evaporation.

Water: $v' = 0.00112 \frac{m^3}{kg}$

Benzene: $v' = 0.00143 \frac{m^3}{kg}$

$$v'_{water} = 0.00112 \frac{m^3}{kg} \cdot 0.181 \text{ kg} = 0.0002 \text{ m}^3$$

$$v'_{benzene} = 0.00143 \frac{m^3}{kg} \cdot 0.819 \text{ kg} = 0.0012 \text{ m}^3$$

These two volumes add up because the two liquids displace each other. This leads to

INTERMEDIATE RESULT **A.3:**

$$v' = 0.0014 \frac{m^3}{kgMixed \ steam}$$

A.4 CALCULATING THE EVAPORATION HEAT AT 450 K

The intermediate results, i.e.

Intermediate result **A.1:** $\left(\dfrac{dp}{dT}\right)_{total} = 39.13 \; \dfrac{kPa}{K}$

Intermediate result **A.2:** $v'' = 0.0363 \; \dfrac{m^3}{kgMixed \; steam}$

Intermediate result **A.3:** $v' = 0.0014 \; \dfrac{m^3}{kgMixed \; steam}$

are to be put into equation (2):

$$r_{450} = 39.13 \; \frac{kPa}{K} \cdot (0.0363 - 0.0014) \; \frac{m^3}{kg} \cdot 450K = \frac{kNm}{kg}$$

FINAL RESULT **A:** $\quad r_{450} = 614.5 \; \dfrac{kJ}{kg}$

APPENDIX B:

CALCULATION OF THE EVAPORATION HEAT OF THE MIXED STEAM AT 350 K

The same calculation method is adopted here as in Appendix A.

B.1 DETERMINING THE GRADIENT OF THE STEAM PRESSURE CURVE AT 350 K

Table values for water at 350 K :

Evaporation heat $\quad r = 2316 \; \frac{kJ}{kg}$

Steam volume $\quad v'' = 3.847 \; \frac{m^3}{kg}$

Liquid volume $\quad v' = 0.001 \; \frac{m^3}{kg}$

With equation (8):

$$\left(\frac{dp}{dT}\right)_{water} = \frac{2316 \; \frac{kJ}{kg}}{(3.847 - 0.001) \; \frac{m^3}{kg} \cdot 350K} = 1.7205 \; \frac{kPa}{K}$$

Table values for benzene at 350 K

Evaporation heat $\quad r = 399.7 \; \frac{kJ}{kg}$

Steam volume $\quad v'' = 0.3971 \; \frac{m^3}{kg}$

Liquid volume $\quad v' = 0.0012 \; \frac{m^3}{kg}$

With equation (8):

$$\left(\frac{dp}{dT}\right)_{benzene} = \frac{399.7 \; \frac{kJ}{kg}}{(0.3971 - 0.0012) \; \frac{m^3}{kg} \cdot 350K} = 2.8846 \; \frac{kPa}{K}$$

Both results put into equation (7)

$$\left(\frac{dp}{dT}\right)_{total} = 1.7205 + 2.8846 = 4.6051 \; \frac{kPa}{K}$$

INTERMEDIATE RESULT **B.1**: $\left(\frac{dp}{dT}\right)_{total} = 4.6051 \; \frac{kPa}{K}$

B.2 DETERMINING THE STEAM VOLUME AT 350 K

The steam composition must be determined beforehand.

When the table values for the steam pressure, i.e.

water $\quad p = 0.416 \; bar$

benzene $\quad p = 0.917 \; bar$

are put into equation (6), the steam pressure of the mixed steam is obtained.

$$p_{total} = 0.416 + 0.917 = 1.333 \; bar$$

According to equation (9), this then supplies the mole fractions of the individual components, i.e.

$$x_{water} = \frac{0.416 \; bar}{1.333 \; bar} = 0.312 \; \frac{mol}{mol}$$

$$x_{benzene} = \frac{0.917 \; bar}{1.333 \; bar} = 0.688 \; \frac{mol}{mol}$$

Converted according to equation (10)

$$x_{water} = 0.312 \; \frac{mol}{mol} \qquad w_{water} = 0.0947 \; \frac{kgwater}{kgSteam}$$

$$w_{water} + w_{benzene} = 1 \qquad w_{benzene} = 0.9053 \; \frac{kgbenzene}{kgSteam}$$

During the course of the adiabate from (2) to (3) (Fig. 2) no amount of substance can get lost. This means that the benzene quantity of 0.819 kg in the steam is preserved. The water quantity also remains unchanged, but is now split up into water steam and precipitated water (as mist). The quantity of water precipitated must be such that the above-calculated concentration in the steam is obtained. This then leads to the following equations for the condition at the end of the adiabate.

Water steam $+$ *water mist* $= 0.181\ kg$ (starting quantity)

Benzene steam $= 0.819\ kg$ (starting quantity)

The quantity of water steam which now exists results from the ratio of the two weight fractions.

$$\frac{w_{water}}{w_{benzene}} = \frac{M_{water}[kg] \cdot (M_{water}[kg] + M_{benzene}[kg])}{(M_{water}[kg] + M_{benzene}[kg]) \cdot M_{benzene}[kg]}$$

$$= \frac{M_{water}[kg]}{M_{benzene}[kg]}$$

$$M_{water\ steam}\ [kg] = \frac{w_{water}}{w_{benzene}} \cdot M_{benzene\ steam}\ [kg] \qquad (12)$$

$$M_{water\ steam}\ [kg] = \frac{0.0947\ kg}{0.9053\ kg} \cdot 0.819\ kg = 0.0857\ kg$$

The water quantity of 0.181 kg existing in the cycle process is hence split up into 0.0857 kg of still existing steam and 0.0953 kg of precipitated water. This is more than half of the water quantity which originally existed in the mixed steam. This enormous water share passes its condensation heat on to the benzene steam which, for its part, delivers this energy as mechanical work to the piston. This internal heat exchange is the crucial mechanism which leads to the astonishing final result.

At a temperature of 350 K (point 3 in Fig. 2), one kilogramme of mixed steam hence consists of:

water steam:	0.0857 kg
liquid water:	0.0953 kg
benzene steam:	0.8190 kg

The following table value is required for calculating the steam volume at 350 K:

$$v''_{water} = 3.847\ \frac{m^3}{kg}$$

$$v''_{benzene} = 0.3971\ \frac{m^3}{kg}$$

which must be multiplied by the respective weight shares in the steam.

Volume of the water steam:

$$3.847\ \frac{m^3}{kg} \cdot 0.0857\ kg = 0.3297\ m^3$$

Volume of the benzene steam:

$$0.3971\ \frac{m^3}{kg} \cdot 0.819\ kg = 0.3252\ m^3$$

These two values should also be identical, but differ around 1.4% from each other. At a lower pressure, the difference between the steams from the ideal gas is, as expected, smaller than at 450 K. In this case too, the mean value of the two results is used for the further calculation.

INTERMEDIATE RESULT **B.2:** $\qquad v'' = 0.3275\ m^3$

B.3 NEGLECTING THE LIQUID VOLUME AT 350 K

In view of the large steam volume, the liquid volume v' can be neglected here.

B.4 CALCULATING THE CONDENSATION HEAT FROM POINT 3 TO POINT 4 (FIG. 2) AT 350 K

In order to calculate the condensation heat, the intermediate results obtained can be put into equation (2).

INTERMEDIATE RESULT **B.1:** $\quad \dfrac{dp}{dT} = 4.6051 \ \dfrac{kPa}{K}$

INTERMEDIATE RESULT **B.2:** $\quad v'' = 0.3275 \ \dfrac{m^3}{kgMixed \ steam}$

The water share already precipitated was calculated in conjunction with the composition balance of the mixed steam at point 3 in section B.2 on page 16. This water share has already reached point 4 (same pressure, same temperature). The dimension m_/kg of mixed steam here refers to the total quantity circulating in the process.

$$r_{350} = 4.6051 \ \frac{kPa}{K} \cdot 0.3275 \ m^3 \cdot 350K$$

FINAL RESULT **B:** $\quad r_{350} = 527.9 \ \dfrac{kJ}{kg}$

APPENDIX C:
CALCULATING THE LIQUID PRE-HEATING FROM 350 K TO 450 K

The values for the liquid pre-heating can be calculated and added up separately for water and benzene because the two liquids separate from each other. The specific temperature rise of the liquids results from the respective enthalpy difference between 450 K and 350 K.

Table values for water:

$$h'_{450} = 749.4 \ \frac{kJ}{kg}$$

$$h'_{350} = 321.8 \ \frac{kJ}{kg}$$

$$h'_{450} - h'_{350} = 427.6 \ \frac{kJ}{kg}$$

Table values for benzene:

$$h'_{450} = 47.5 \ \frac{kJ}{kg}$$

$$h'_{350} = -160.0 \ \frac{kJ}{kg}$$

$$h'_{450} - h'_{350} = 207.5 \ \frac{kJ}{kg}$$

These values must be multiplied by the liquid quantities from which one kilogramme of steam is produced. In Appendix A, these quantities were calculated as follows:

Water: $0.181 \ kg$

Benzene: $0.819 \ kg$

This means for the temperature rise:

Water: $427.6 \ \frac{kJ}{kg} \cdot 0.181 \ kg = 77.4 \ kJ$

Benzene: $207.5 \ \frac{kJ}{kg} \cdot 0.819 \ kg = 170 \ kJ$

Adding up the two values gives the:

liquid pre-heating = 77.4 + 170 = 247.4 kJ

FINAL RESULT **C:**   *Liquid pre-heating = 247.4 kJ*

14 REFERENCES

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[3] Thermodynamik, Physikalisch-chemische Grundlagen der thermoschen Verfahrenstechnik, Lüdecke Lüdecke, Springer 2000, ISBN 3-540-66805-5.

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