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THERMOACOUSTIC SCHOOL PROJECT

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Abstract: Teaching Science can only be successful if we are able to answer the challenges of the 21st century. Teaching Physics, Chemistry and Biology with the traditional methods is unintelligible and considered unnecessary for most students. This situation needs to be changed. Students can only develop their abilities and skills to the full extent and can only deepen their knowledge when they are surrounded by an atmosphere which is motivating and encouraging for their personality. The establishment of this motivating atmosphere is the task of the teacher mainly joining up with parents. Out of the wide range of innovative options, in this article I deal with the teaching and learning of Science through project works at school. We can give students, for instance, more complex project works where besides Physics they have to go into the matter of Biology or other Science subjects. While they are searching for information, they use the Internet and at the end they produce a presentation and at the same time they develop their informative-communicative skills. So all things considered, students are affected positively from more sides while working on the project work. At first, I survey the recent situation of teaching Science then I present a particular project work in which we can examine thermoacoustic phenomena with cheap and easy-to-prepare tools at school.

Zusammenfassung: Der Unterricht der Naturwissenschaften kann nur erfolgreich sein, wenn man fähig sein wird, die Herausforderungen des 21. Jahrhunderts zu beantworten. Die auf die traditionelle Art und Weise unterrichteten Fächer Physik, Chemie, und Biologie gelten für die meisten Kinder als überflüssige, unverständliche Last. Das muss auf jeden Fall verändert werden. Die Fähigkeiten und Fertigkeiten der Kinder können sich nur optimal entfalten, ihr Wissen kann sich nur dann vertiefen, wenn ihre Persönlichkeit ständig von einem stimulierenden, ermunterndem Umfeld umgeben wird. Das Schaffen dieser motivierenden Umgebung gehört vorwiegend zu den Aufgaben der Pädagogen natürlich in Zusammenarbeit mit den Eltern. Unter den zahlreichen innovativen Möglichkeiten befasse ich mich in diesem Artikel mit dem projektmässigen Unterrichten und Lernen. Wir können den Schülern zum Beispiel eine kompliziertere Projektaufgabe geben, bei der sie neben Physik, Biologie oder nach anderen naturwissenschaftlichen Kenntnissen recherchieren müssen. Beim Recherchieren benutzen sie das Internet, am Ende machen sie eine Präsentation, sie entwickeln ihre informative-kommunikative Kompetenzen, also sie bekommen während der Projektarbeit mehrere positive Eindrücke. Zuerst behandle ich die aktuelle Lage des Naturwissenschaftenuterrichtes, dann werde ich eine Projektaufgabe vorstellen, bei der wir mit der Benutzung von einfachen und preiswerten Mitteln in der Schule thermoakustische Erscheinungen untersuchen können.

Key words: thermoacoustic, experiment, project work

1. Introduction

The Rocard Committee (president: Michel Rocard; members of the expert group: Peter Csermely of Semmelweis University, Budapest; Doris Jorde of the University of Oslo; Dieter Lenzen, President of the Freie Universität Berlin and Harriet Wallberg-Henriksson, President of Karolinska Institutet, Stockholm) made a report in 2007 about the science education system of EU. The Rocard report [1], in accordance with other studies, has highlighted an alarming decline in young people's interest for key science studies and mathematics. Despite the numerous projects and actions that are being implemented to reverse this trend, the signs of improvement are still modest. Unless more effective action is taken, Europe's longer term capacity to innovate, and the quality of its research will also decline. Among the population in general, the acquisition of skills that are becoming essential in all

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walks of life, in a society increasingly dependent on the use of knowledge, is also under increasing threat.

The origins of the declining interest among young people for science studies are found largely in the way science is taught in schools: in most European countries, science teaching methods are essentially deductive. The presentation of concepts and intellectual frameworks come first and are followed by the search for operational consequences, while experiments are mainly used as illustrations. A change is under process in some countries towards more extensive use of inductive methods: „*a reversal of school science-teaching pedagogy from mainly deductive to inquiry- based methods provides the means to increase interest in science*" [1].

The "*inductive approach*", most often referred "*inquiry-based science education*" (IBSE), has proved its efficacy at both primary and secondary levels in increasing children's and students' interest and attainments levels while at the same time stimulating teacher motivation. The two approaches (deductive and inductive) are not mutually exclusive and can and should be combined in any science classroom to accommodate for different kinds of scientific topics, different mindsets and age groups preferences.

The Rocard Committee had some recommendations [1]:

- Improvements in science education should be brought about through new forms of pedagogy; the introduction of inquiry-based approaches in schools should be actively promoted and supported.
- Priority given to initiatives that include a large diversity of practices in science teaching to respond to the diverse needs of children: problem based inquiry process; hands-on/minds-on activities; teamwork.
- Idependent work on open-ended questions; trans-disciplinary activities; showing relevance of science content.
- Teachers are key players in the renewal of science education. Among other methods, being part of a network allows them to improve the quality of their teaching and supports their motivation.
- Collaborative science education initiatives within the EU in order to identify effective and innovative techniques that show potential for increasing interest towards science and which could be used as models for future policies.
- Reduced need of specific materials for cost sustainability.

Providing all EU citizens with both science literacy and positive attitude towards science, every citizen with the skills needed to live and work in the knowledge society by giving them the opportunity to develop critical thinking and scientific reasoning that will enable them to make well informed choices. Science education helps fighting misjudgements and reinforcing our common culture based on rational thinking. The report recommends that "*teaching should concentrate more on scientific concepts and methods rather than on retaining information only*" and that stronger support should be given to teacher training in science [1]. The science education community mostly agrees that pedagogical practices based on inquiry-based methods are more effective, than the deductive one; but in the majority of European countries these methods are simply not being implemented.

In this article I present a project type of physical measuring and examination task. The aim of our project is while students enlarge their knowledge about thermo acoustics; on the one hand they develop their applied information technologic skills, while on the other their cooperative skills are improving as well. Our school project promote a pedagogy using an inquiry-based approach that succeeds to develop excitement around science; presents the processes and methods of science together with its products and promote a wide range of practices including inquiry based activities, hands-on/minds-on and group projects.

2. The Rijke tube

The Rijke tube is a simply pipe with both ends open and a heat source placed inside; the heat source may be a gas-flame. If the tube is positioned vertically and the heat source is introduced from below into the tube, turns on position of the heat source within the tube, the Rijke tube can emit sound. Rijke pipe converts heat into sound by creating a self-amplifying standing wave, this thermoacoustic phenomenon is an excellent example of resonance.

2.1. Rijke sounding mechanism

Petrus Leonardus Rijke was a professor of physics at the Leiden University in the Netherlands. In 1859 he discovered a way of using heat to sustain a sound in a tube open at both ends. Inside the pipe, about fourth from below, he placed a wire grid and heated the gauze with a flame until it was glowing red hot. Removing the flame, he obtained a sound from the tube which lasted until the gauze cooled down. (Rijke received complaints from his university colleagues because the sound was loud and could be easily heard three rooms away from his laboratory.)

The earliest explanation for the sounding mechanism was provided by Rijke himself [3]: Rijke suggested that the hot gauze transferred heat to the adjacent volume of air in the tube, which then expanded, became less dense, and started rising up the tube, thus setting up a mean upward flow of air in the tube. The rising volume of air on coming in contact with the cooler walls of the upper half of the tube, subsequently contracted and became more dense, thereby setting up a variation in density along the length of the tube. According to Rijke, the resulting variation in pressure was such that, fluid elements in the lower half of the tube always experienced expansion, while those in the upper part of the tube always underwent compression. The acceleration and deceleration of the gas molecules are sinusoid; the result is a self-sustained series of longitudinal sinusoidal air pressure oscillations [5]. Stationary acoustic waves in tubes can be easily set up by any source of energy, but once the source of energy is discontinued, the acoustic waves usually damp out due to friction within the tube, and due to energy being lost at the open ends of the tube. The role of the energy source in a sounding Rijke tube is not merely to excite acoustic waves in the tube but also to build up and sustain the already excited acoustic waves [3].

2.2. Rayleigh's Criterion

In 1878 Lord Rayleigh (John William Strutt, 3rd Baron Rayleigh) had formulated a criterion to explain how acoustic waves could be excited and sustained by heat addition: *"If heat be communicated to, and abstracted from, a mass of air vibrating (for example) in a cylinder bounded by a piston, the effect produced will depend upon the phase of the vibration at which the transfer of heat takes place. If heat be given to the air at the moment of greatest condensation, or be taken from it at the moment of greatest rarefaction, the vibration is encouraged. On the other hand, if heat be given at the moment of greatest rarefaction, or abstracted at the moment of greatest condensation, the vibration is discouraged''* [2].

The flow of air past the grid is a combination of two motions: there is uniform upwards motion of the air due to a convection current resulting from the gauze heating up the air; superimposed on this is the motion due to the sound wave. For half the vibration cycle the air flows into the tube from both ends until the pressure reaches a maximum. During the other half cycle, the flow of air is outwards until the minimum pressure is reached. All air flowing past the mesh is heated to the temperature of the gauze and any transfer of heat to the air will increase its pressure according to the gas law, so reinforcing the vibration; so this effect is called „*sonically induced heat gradient*". During the other half cycle, when the pressure is decreasing, the air above the gauze is forced downwards past the gauze again; for it is already hot, no pressure change due to the réseau takes place, since there is no transfer of heat. The sound wave is therefore reinforced once every vibration cycle and it quickly builds up to very large amplitude.

The Rayleigh's criterion refers only to the time-varying component of heat transfer q'; it states that if heat is added ($q'>0$) during the compression half cycle ($p'>0$) or taken out ($q'<0$) during an expansion half cycle ($p'<0$), then the acoustic waves would be sustained [3]; the criterion can be formulated with the help of Rayleigh-integral:

$$I = \frac{1}{T}\oint p'q'\,dt,$$

where T is the time period of oscillations, p'is the acoustic pressure, q'is the fluctuation in heat transfer, and t is time:

- if $I<0$, then acoustic oscillations will damp out,

- if $I>0$, then acoustic oscillations will grow,
- if $I=0$, then oscillations will neither be damped out nor amplified [3].

3. The school project

We need the following tools for the measurements:

- Rijke tube with a bearer (we used 2 aluminium tubes, 1 brass tube and 1 glass tube as well, because it is easy to demonstrate the position of wire obstacle on that).
- A gas-burner (with controllable efficiency).
- Wire obstacles (wire netting – which match the tubes with given diameters; with different grating – so that this could be analyzed as well).
- For length measurement: tape measure or ruler.
- For timing: stopper.
- A tool for recording and measuring sound (e.g. a microphone and a computer with sound card).
- Thermometer, which can be used by a temperature of more hundred °C (expectedly the values to be measured will be in a range of 200-1000 °C).
- Equipment for the current of air (e.g. a hoover).
- A sound level meter, which we need only for the quantitative results, otherwise the experiment can be done without it too. We used a noise level meter 322 Datalog typel; we borrowed the instrument from University of Szeged, for which we render thanks. The Sound Level Meter 322 measures the sound level impacting the built-in electret condenser; it is suitable as a test instrument for laboratory use or for scientific purposes to measure sound levels in general field testing up to an intensity of 130 dB. The unit has a built-in data logger function, i.e. the unit can automatically record measured values at specific recording intervals. The stored values can be read via software immediately or later. The unit has two weighting filters:
  - Weighting per the A curve enables the unit to evaluate frequencies as does the human ear, which perceives loudness differently in different frequency ranges. (The A weighting is selected for general measurements, for example for measurements of the working environment.)
  - Weighting per the C curve enables a measurement without corresponding lift or attenuation in specific frequency ranges. The C weighting is used for measurements for determining the loudness of machines and engines, for example; so we choiced the C curve for our experiments.

  During the measurement the meter was fixed to avoid vibration and movement, the unit was placed 10 cm sideways from the Rijke tube, in order to avoid operation under unfavourable ambient conditions, since the excessive ambient temperatures would lead to damage to the sensitive electronics within sensor. While we were carrying out measurements, we always align the microphone precisely towards the sound source to be measured and we take care that no objects come between the microphone and the sound source.

Some of these tools (tube, stand, gas-burner, wire mesh) can be found in every physics laboratory at schools, and the other part of them (microphone, computer with sound card, hoover) can also be found in educational institutes); accordingly, these cost not further money. Currently the infrared thermometer (which is used for the measuring of temperature) costs approx. 80 EUR, but similar thermometer can be found in many schools. We borrowed the sound level meter for the duration of measurements; a similar equipment costs approx. 200 EUR. A cheaper kind of this instrument exists as well, that does not store the measured data, but for the experiment this one is fine too. Fortunately we don't necessarily need this tool, eventually the microphone and the computer will do so that we can ascertain the relative loudnesses – of course in this case we can not count directly with numerical values. I highlight this, so that we see that the performance of these measurements does not require extra expenditure of the school, which corresponds with the statements of the Rocard report.

In the course of the measurements we were looking for the answer for the following relationships:

- How do the length of the tube and the status of the heat source influence the formation of sound?
- How does the altering of heat output influence the sound?
- How much does the sound depend on the temperature can be measured inside the tube (the temperature of the réseau)?

- If there is a separate air current in the tube as well, how does that influence sound emission?

3.1 Experimets in the school project

The students from our secondary school were invited to volunteer in this project. We carried out the measuring in the afternoons on extracurricular Physics classes. We executed the experiments in team works and each team consisted of 3-6 students. On the picture 1 given measuring arrangements can be seen.

Picture 1. *Vertical Rijke pipe with measuring arrangement (a) copper tube; (b) shorter aluminium tube*

In the course of the measurements we were working with 4 different Rijke tubes. The parameters of the tubes used under the experiments can be found in the table 1.

Table 1. *The parameters of the pipes in our school project*

Rijke tube	Material	Length (L) [mm]	External diameter [mm]	Internal diameter [mm]	Emission degree (ε)
1.	glass	380	30	28	0.95
2.	copper	470	29	27	0.83
3.	aluminium	768	50	40	0.90
4.	aluminium	1502	100	94	0.89

Each of the teams examined the behaviour of different tubes and shared some of the utensils (i.e. the sound level meter, infrared thermometer). It needed specific organization. In addition to this, we had to be careful that the Rijke pipe did not disturb the work of the other team. (Before going deep into the topic it is worth devoting some time to make a plan for the process before its actuation.) The work of the teams had to be harmonized as we shared a finite number of resources and had to work without the distraction of others. With this aligned work we additionally improved the students' organizing skills, moreover their social competence is developed (sharing the tools). (While at the beginning they could not agree who uses what, later it went fluently.) We repeated every measuring five times and counted with the average rate; we recorded the results on computers.

3.2. The course of measuring

At first we had to determine the efficiency of the gas-burners (we used gas-burners of 3 different types). The measuring of power was traced back to the measuring of temperature change and timing: we were warming water of a defined mass and zero temperature until reaching the boiling point; thus we were able to count out the temperature change easily. Knowing the specific heat of water (c_{water}) we can count out the change of internal energy. Let's mark the power of the gas-burner in stage '*i*' with P_i. In this burn-stage we did 2 measurements, the first one lasted t_{i1}, the second one lasted t_{i2} time. Let's mark the mass of water m_{i1} in the first case, and m_{i2} in the second case; and the temperature changes will be marked by ΔT_i.

We get the power of the gas-burner in stage '*i*': $P_i = \dfrac{c_{water} \cdot (m_{i2} - m_{i1}) \cdot \Delta T_i}{t_{i2} - t_{i1}}$.

The second step was the definition of the transmissivity of the wire mesh put into the Rijke tube. Our first idea was to tie a hoover to the tube, and then we measure the volume of air flowing during a given time – first while the wire netting is in the tube, and then while there is no wire netting in it. The rate of the two measurements gives the transmissivity of the wire mesh. Unfortunately this method did not work in practice, since there was no measurable difference between the two cases; therefore we chose another method. We made a digital photo of the mesh in supermacro mode, then we measured the size of one empty square and we counted the number of such squarebars in the tube (taking the deformed squares on the brink as half), then finally we totalized their territories. The quotient of the total empty territory and the cross-section of the tube give the transmissivity of the wire mesh. The transmissivity of the 3 different meshes came about 68%, 78% and 85% one after another. We did measurements with all of the 3 wire meshes. We did not really find significant deviations. We found that the material of the wire mesh counts a lot more; however all of the meshes were made of steel (steel alloy), the densest one seemed to be the most appropriate. If the power of the gas-jet was too big, then of course any meshes were melted and this way became unusable for the experiments. Consequently it is practical to use some sort of a flexible mesh with a higher melting-point.

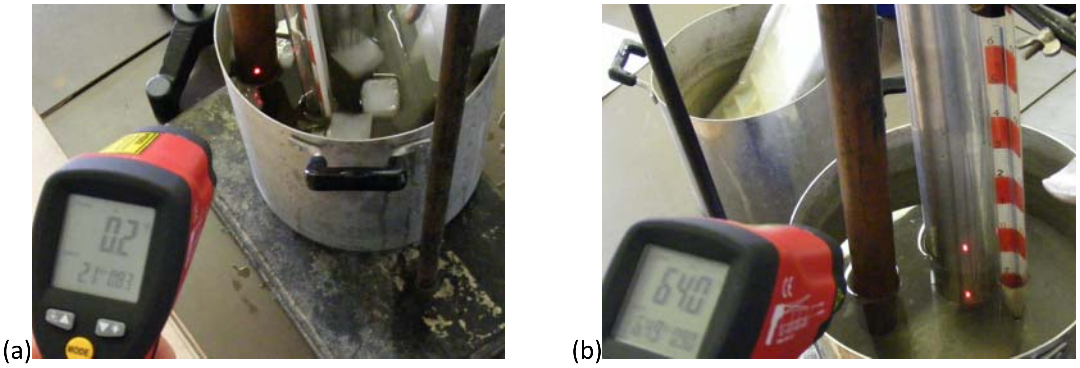
Measurement of temperature

We used an infrered thermometer. The IR-380 infrared thermometer is precise non-contact measurement unit with built-in laser pointer, it measure the surface temperature of an object. The unit's optics sense emitted, reflected, and transmitted energy, which is collected and focused onto a detector.

Adjustment of emissivity

Emissivity (ε) is defined as the ratio of the energy radiated by an object at a given temperature to the energy emitted by blackbody, at the same temperature. (The emissivity of a blackbody is 1; all values of emissivity fall between 0 and 1.) The IR-380 infrared thermometer has the ability to compensate for different emissivity values, for different materials. In general, the higher the emissivity of an object, the easier it is to obtain an accurate temperature measurement using infrared.

The emissivity depends on the material and on the quality (texture) of the surface. The emissivity of most of the organic materials or oxygenated surfaces is around 0.95; the emissivity of metallic surfaces or gleaming subjects is smaller; the shape, the quality of surface and other parameters can influence the emissivity. The instrument has an emissivity-tuning function that makes the more exact measure possible. To define the emissivity of a subject made of a given material, we should know its temperature in advance then we should modify the ε value on the infrared thermometer until the thermometer itself indicates the same temperature. Therefor we poured water into a big pot then we put the different tubes, the mesh and the thermometer into this pot, so that they sink into the water half-way. We dosed ice into the pot until it did not melt any more that is until the temperature of ice water with the bodies in it was 0 °C. After this we slowly started to warm the pot, until the water reached it boiling-point. In the meanwhile we were measuring the emissivity of each body on their parts above the water (picture 2).



Picture 2. *The instrument has an emissivity-tuning function that makes the more exact measure possible. (a) Temperature of copper tube is 0 °C in ice-water mix and the infrared thermometer show 0.2 °C by* $\varepsilon=0.83$. *(b) Temperature of aluminium tube is 64 °C and the infrared thermometer show the same value by* $\varepsilon=0.9$.

The results we got can be seen in the table 1. (At the case of the steel meshes a value of 0.85 came about.) After this the measurement of temperature seemed to be simple. We were able to measure the external temperature of the tubes very easily, but the definition of the temperature of the wire mesh was quite problematic. On one hand, at times we exceeded the instrument's upper measurement limit, that is we only knew that the temperature of the wire grid is higher than 800 °C, but we didn't know the exact value. On the other hand, it also caused some problem, with the aimig laser of the measuring instrument to focus on the wire mesh, since we could not put the thermometer directly above the tube, because the rising volume of air would have melted it, therefore we had to measure it a little slantwise, from the side. In this case, however, the smallest excursion of the instrument could cause that in the next moment the focus was not on the wire mesh any more. This could be seen on the results. In the measurement series the biggest fluctuation came about in the course of the measuring of the temperature of the réseau, considering the measures with equal parameteres. It often occured, that in two unchanged, sequential measures there was a difference of 15-20% in the temperature of the wire mesh. In the case of other quantities to be measured we did not find this level of uncertainty.

The definition of the intensity of perfused air

In some of the experiments we ensured a separate air current with the help of a hoover; the sucking power of which was counted out by blowing up a bigger (approx. 50 l) plastic bag then we sniffed the smaller part of the air out of it for a short time. We got the sucking power ($\Delta m/\Delta t$) out of the gas law: $\Delta m = \frac{p \cdot M \cdot \Delta V}{R \cdot T}$, where T is the temperature in Kelvin (it was 293 K in our experiment), and p is the pressure of air ($p=10^5$ Pa). We supposed, that the pressure is about constant, since we sucked out only a little air; that is, it was enough to measure only the volume change of the bag. For the sucking power of the hoover 0.9 g/s came about from this.

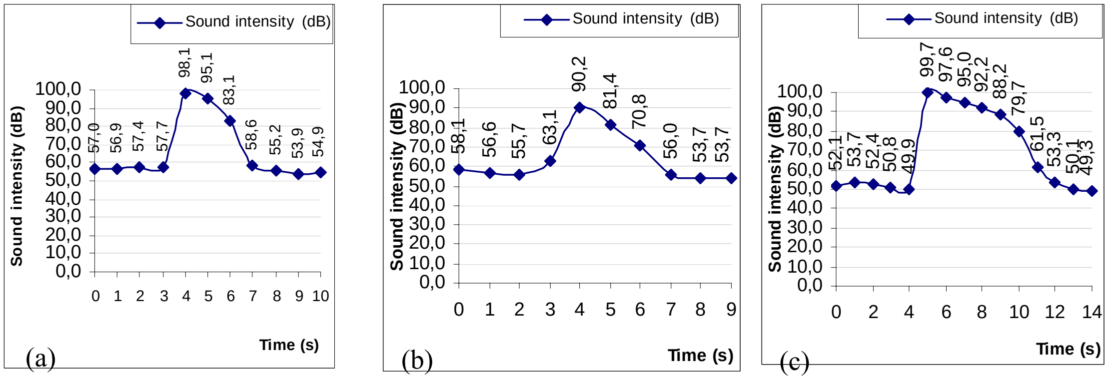
3.3. Threshold Effect

If we start to warm the wire mesh inside the tube (which is in a vertical position) with gas-jet, the grid is going to get hot in a short time. If we continue to do the warming (with the same power), the temperature of the mesh is not going to get much higher, at least this is what we experienced inside the measuring exactitude. If in the meanwhile we are examining the sound issued by the Rijke tube, we can observe that the duration of the sound emission has a very easily perceptible maximum. The issued sound will be the longest just about when the wire mesh reaches the bottom of the temperature platform in the course of the warming. Therefore even if we keep warming the réseau, the issued sound will not last longer, moreover, after this point it starts to decrease; that is, there is an optimal time duration until it is effective to warm the mesh, if our goal is to hear the sound formed in the Rijke tube for a longer time. If we measure the temperature of the end of the tube as well during the experiment, we can find that it is constantly growing, depending on the material and the geomatrical size of the tube (indirectly on its mass), the intensity of warming, and the postition of the wire grid.

We examined the sound in function of the temperature difference between the réseau and the end of the pipe; and we can say, that the duration of the issued sound depends on the temperature difference between the mesh and the end of the tube, that is: $t_{sound} = t_{sound}\,(T_{mesh}-T_{end\ of\ tube})$.

The reason according to Entezam and cooworkers is that in the Rijke pipe the mesh (the source of heat) heats the surrounding air and causes it to rise. "*Acoustically induced particle displacements are superimposed on the naturally convected steady flow. When acoustic particle displacements are positive upward, fresh cold air crosses the heated grid, but when negative, hot air from above is filtered through.*" During the upward motion, maximum heat transfer occurs between the réseau and the air due to the large temperature difference between the heat source and the cooler air. Since the timing in the acoustic cycle is such that maximum heat transfer corresponds to a positive particle displacement (with favorable upward motion), an ideal situation is created to promote acoustic wave growth according to Rayleigh's criterion, i.e. acoustic excitation is efficiency when heat is added to an acoustic wave at the high temperature phase of its cycle [4].

We examined the sound emission of the tube in case of different burning powers as well. In this case the position and transmissivity of the wire mesh did not change. After warming it for a given period of time, we measured in case of each heating power and each grid position. In the time dependence of the issued sound we can experience that there is an optimal warming time, after which neither the duration, nor the intensity of the issued sound will further grow. As for the position of the wire mesh, we started at the bottom of the tube and after each measurement series we always put the réseau upper and upper – jumping approx. 1-2 cm at a time. The duration and intensity of the issued sound was gradually growing as well, until we came near the quarter of the tube. The maximum of both the sound intensity and the duration of the sound can be found about at the $x=L/4$ place (picture 3).



Picture 3. *The maximum of both the sound intensity and the duration of the sound can be found about at the x=L/4 place. (a) glass tube, power of heat was approx. 300 W; (b) brass tube, power of heat was approx. 340 W; (c) shorter aluminium tube, power of heat was approx. 430 W.*

Location of the mesh

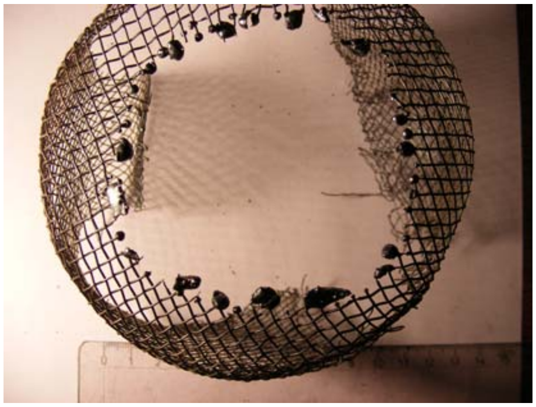
We find that oscillations reach maximum amplification when the grid is placed in the bottom half about at fourth of pipe. If we located the réseau further from the quarter of the tube, the values of both the sound intensity and the duration of the sound were decreasing. It is interesting, that the behaviour of the first and second quarter of the tube is not symmetric. In the second quarter the values were decreasing faster than they were increasing in the first quarter. Near to the half of the tube we get to a point where the tube does not emit sound anymore. We changed the duration or power of warming in vain, there was no sound issued in the Rijke tube.

3.4. Sound emission in function of the power of the gas-burner

Keeping the réseau at the ideal position in pipe ($x=L/4$), we released different heat power levels. If we characterize the sound emission in function of the power of the gas-burner, we are going to experience a threshold-like behaviour. In case of a too low power input (approx. $P<100$ W) none of the tubes issued any sound. We were trying to sound the tubes with candle flame and also with the flame of a Bunsen-burner, but we did not succeed. The reason for that may be that these flames could not properly warm up the wire mesh. In the case of the smaller gas-burner, though, with the help of just a little bit bigger power input (approx. P>130 W) than in the previous case, we already managed to make the two smaller tubes issue a sound (picture 4).

Picture 4. *Threshold-effect in the heat power: in case of a too low power input (candle light) none of the tubes issued any sound, but just a little bit bigger power input (gas-jet) was enough to generate sound*

The shorter aluminium tube issued a sound when using at least 150 W high power input. Gradually increasing the power and also the time of the warming separately, we will get to an optimal point, where the sound issued by the tube can be heard for the longest time. This means a power value between 300-500 W – depending on the tube and the grid position. If we continue to increase the power input, after a while not only the length of the sound will decrease, but the sound emission is going to fully cease. There are two possible reasons for that: on one hand, the high burning power results in increase of the speed of the air flowing in the tube, which is a bar to the formation of sound waves; on the other hand, a too high burning power simply melts the wire mesh, and by this the sound creating „energy pump" is going to cease (picture 5). In this case, the temperature of the wire mesh probably exceeded the 1500 °C, since the melting temperature of steel is about this value.



Picture 5. *Too high burning power melts the wire mesh*

We did not manage to „sound" the 1.5 m long aluminium tube. In none of the cases was any sound issued, and the reason for this probably is that while using lower power input we did not even reach the necessary low threshold, but when using higher power, we already overstepped the proper power range. (That is, either the air current was too powerful in the tube, or the mesh was simply burnt away.) Unfortunately we found that neither the biggest gas-burner (the so-called „pig-scorcher"or „pig-singer") proved itself to be proper, since we could not control fine its power (picture 6).

Picture 6. *We did not manage to „sound" the longer aluminium tube with the „pig-singer"*

In spite of that it was really spectacular that it is able to shoot out a may as well 1,5 m long jet (we tried this out in the courtyard, of course), the power of which exceeds the 4 kW, buti in a classroom you can not really use that. This is why, after many failures, we decided not to use the biggest tube and the „pig scorcher" for the further measurements, and we continued to work only with the three smaller tubes. The summary of the threshold effect can be found in the table 2.

Table 2. *We warmed the shorter aluminium tube in vertical position, using different power inputs, with x=L/4 (optimal) mesh position.*

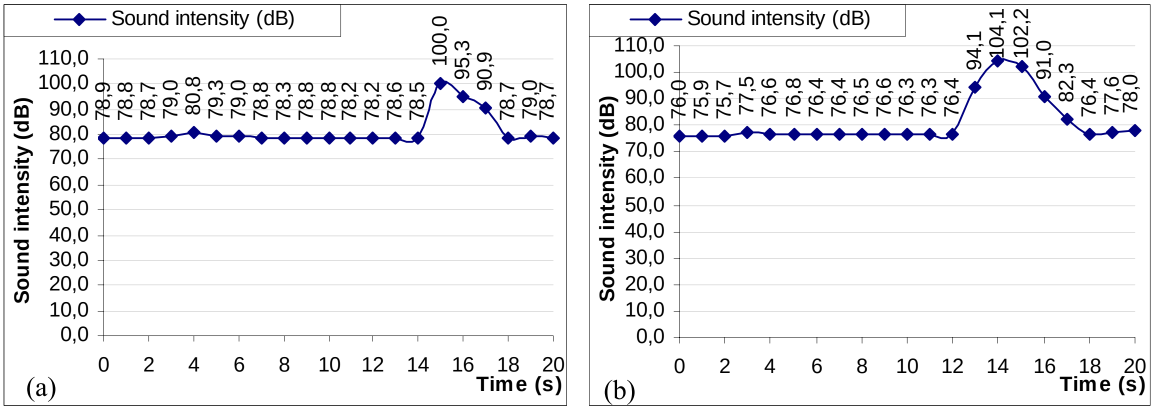
Power of heat-jet (W) (approx.)	80	120	200	400	550	720	960
Without extra air-flow	-	-	+	+	+	+	-
With extra air-flow	-	+	+	+	+	-	-

We were warming the tube (which was in a vertical position) from the bottom, using different power inputs, with $x=L/4$ (optimal) mesh position. At first there was only natural air current in the tube, but in the second measurement series we ensured a separate, second air current as well, by sucking the Rijke tube from the top, with the help of a hoover. (The „+" sign in the table means that there was a sound issued in the Rijke tube, and we put „- „ when we could not perceive the sound.)

3.5 Horizontal tube

If we turn the tube into a horizontal position, and then we try to heat the wire mesh, normally (without a separate air current) there will be no sound issued, since the air does not have a natural convectional flow. We can say that the „*chimney affection*" does not work, and because of this, pressure fluctuation will not evolve either. At this time, neither the mesh position, nor the burning power input matters – the tube will not issue any sound. The situation is different when we ensure another air current in the pipe (with the help of a hoover). In this case there will be an issused sound, moreover, it will be similar to that issued in a tube which is set vertically. The mesh's optimal position is about the $x=L/4$ position and we did not hear any sound in the case of the $x>L/2$ réseau position. Unfortunately, we could not regulate the sucking power of the hoover properly, this is why we can not tell what is the minimal air current intensity by which sound arises in the Rijke-tube, and that what is the highest possible air current intensity, by which there still will be sound issued. It is sure that in this case as well there is a threshold effect. We could demonstrate this by keeping the burning power constant and taking the pipe of the hoover further from the Rijke tube's top (from its mouth), and then we were gradually approaching the tube with the hoover, and this way the air amount flowing in the tube was increasing gradually as well. Initially the tube did not issue any sound, but after a while there was enough air current and the Rijke pipe has sounded.

The hoover was quite loud, this is why in the sound intensity measurements the sound of the hoover was first dominating, but the sound intensity records can be observed well, too, whenever the Rijke-tube issued a sound. It can be seen well that by switching on the hoover the basic sound intensity level increased to approx. 80 dB, but when the Rijke pipe sounded the intensity was nearly the same as it was in the vertical tube, without using a hoover (about 100 dB) (picture 7).



Picure 7. *Switching on the hoover the basic sound intensity level increased to approx. 80 dB, but when the horizontal Rijke-tube sounded the intensity was nearly the same as it was in the vertical pipe, without using extra air-flow. (a) brass tube, heat power was about 330 W; (b) shorter aluminium tube, heat power was about 400 W.*

We experienced, that in the case of a horizontal tube as well, even by optimal mesh position, the upper threshold effect is coming forward. If we increased the power input while the air current intensity was on a maximal level, above a certain value the Rijke-tube did not issue any sound. This upper threshold power depended on the tube we performed the experiment. This upper power limen was the smallest while using glass pipe and it was the highest while using the shorter aluminium tube. (We reckoned this by looking at the size of the jet and also the degree of the tube's warming.) We could not define the exact power values, since even by the given gas-burner degree the burner's power significantly changed because of the jet's horizontal position and because we were sucking the air out of the tube with the help of a hoover. Taking the burner's power by a given degree in vertical jet position and without extra air current was quite worthless for us at this time, because now the change of the circumstances resulted in the significant altering of these values.

If we kept increasing the power input, the meshes were simply melted away, so it is not surprising that no sound was issued at this time at all. To sum it up we can tell that even in the case of a horizontal tube both the low and the upper threshold comes forward in the sound emission. This is dependent on the power of the gas-burner and the intensity of the the air flowing through the tube, and on the position of the mesh as well.

4. Thermoacoustic oscillation in Rijke pipe

A standing wave (stationary wave) is a wave that remains in a constant position; this phenomenon can arise in a stationary medium as a result of interference between two waves traveling in opposite directions. We must solve the following equation [5]:

$$\frac{\partial^2 \psi}{\partial x^2} = \frac{\rho}{\kappa} \cdot \frac{\partial^2 \psi}{\partial t^2},$$

where $\kappa = -V \cdot \frac{\partial \rho}{\partial V}$;

which gives $\psi = A \cdot \cos(\omega \cdot t \pm k \cdot x) + B \cdot \sin(\omega \cdot t \pm k \cdot x)$.

To produce standing waves, two waves (ψ_1 and ψ_2) must be traveling in opposite directions with equal amplitudes, the sum of which is [5]:

$$\psi = 2 \cdot [A \cdot \cos(\omega \cdot t) + B \cdot \sin(\omega \cdot t)] \cdot \cos(k \cdot x).$$

The number of nodes within the tube depends on the harmonic of the standing wave and the boundary conditions. In a tube with two open ends (Rijke tube), the boundary conditions dictate a maximum displacements at the open ends [5]. In this case we can write: $L = \frac{\lambda}{2} \cdot n$, and n=1, 2, 3, 4, … where L is the length of the tube, and n is the harmonic number; the first (n=1) defined as the fundamental harmonic. We can see that the frequency is dependent on the harmonic number, the velocity in the medium, and tube length: $f = \frac{c}{\lambda} = \frac{c}{2 \cdot L} \cdot n$.

Differing from a tube with one closed end (Sondhauss tube), the boundary conditions dictate a maximum displacement at the open end, and zero displacement at the closed end [5]. It follows that only odd numbered harmonics can form. In this case: $L = \frac{\lambda}{4} \cdot (2 \cdot n - 1)$, and n=1, 2, 3, 4, …; the frequency of sound is $f = \frac{c}{\lambda} = \frac{c}{4 \cdot L} \cdot (2 \cdot n - 1)$.

As one would expect, decreasing the length of the tube decreases the wavelength at the fundamental harmonic, and thus equates to a higher frequency (for constant velocity of sound in a gas). As a matter of fact the sound speed was not constant in our experiments, since the temperature and the pressure is changing all the time as well. We were examining the frequency-spectrum of the issued sound with the help of the Audacity 1.3 Beta (freeware) program. We found that the most powerfully sounding frequency of the glass tube was 512 Hz, which is not far from the theoretical fundamental harmonic (460 Hz) frequency. This fundamental harmonic measured value is 453 Hz in the case of a brass tube, its counted value was 329 Hz, and in the case of the shorter aluminium tube the measured frequency is 232 Hz, the counted value was 228 Hz – if we count with c=350 m/s sound speed. It can be seen, that the experimental result is in accord with theoretical value in this instance.The reason for the excursion in the case of the two smaller tubes may be that these tubes got hot sooner, and that significantly changed the sound speed. We also found that besides the fundamental harmonic the first few harmonics are sounding with the highest intensity.

The Rijke pipe may be regarded a "*thermoacoustic pump*" in which the pumping-like temperature oscillations raise the acoustic energy to audible levels. The rate of heat transferred to the air (q) is a function of the temperature of grid (T_{grid}), temperature of ambient air (T_{air}), surface area of the source of heat (the surface of grid= A_{grid}), and the average heat transfer coefficient (h_{avg}). It is defined according to Newton's cooling law: $q = h_{avg} \cdot A_{grid} \cdot (T_{grid} - T_{air})$ [4].

5. Practical applications of thermoacustic phenomena

Finally, it was very important in the students' work to find some kind of a point of interest or newness from the topic of thermoacoustics, and then shortly present it to the others. In the course of the team work the students were searching the Internet for information. I'm going to mention now some if these.

Rijke's original interest in the phenomenon appears to have been from the point of view of musical acoustics. Instead of heating the réseau with a flame, Rijke also tried electrical heating. Making the gauze with electrical resistance wire causes it to glow red when a sufficiently large current is passed. With the heat being continuously supplied, the sound is also continuous and rather loud. However, the response of the pipe did not satisfy Rijke's requirement for musical acoustics.

Combustion in jet and rocket engines involves very high power densities of the order of a GW/m^3, and very small fraction of this energy is more than adequate to excite and sustain acoustic waves inside the combustion chamber – another example of a thermo-acoustic phenomenon. These acoustic waves result in a loud, annoying sound (called screech or buzz) and can also cause structural damage to the combustion chamber. The need to control thermoacoustic phenomena in jet and rocket combustion chambers led to renewed interest in Rijke pipe thermoacoustics [3].

One of the most objectionable constituents of jet engine emissions is NO$_x$. Nitrous oxides emission in combustion processes is proportional to the temperature. It is found that a high ratio of air to fuel in the form of lean, premixed and prevaporized (LPP) flame keeps the temperature of the combustor within acceptable limits. "*However, LPP combustors, beyond a critical fuel-air ratio, tend to show low frequency (50-150 Hz) longitudinal acoustic instabilities, known as 'buzz', which can cause serious structural damage. The Rijke tube, which also shows heat-induced longitudinal acoustic instability, provides a convenient prototypical system for studying the buzz phenomenon in the laboratory"* [3].

Another industrial application where the Rijke phenomenon is relevant is the case of pulse combustors and coal bed combustors. Pulse combustors rely on sustained acoustic instability as a means of improving combustion efficiency by better mixing of fuel and air. In coal bed combustors, almost 70% of the fine ash particles (smaller than 5 microns) can escape through the filtering process. However, it is found that, intense acoustic energy increases the collision rate between these particles, which can help these particles coalesce and increase their effective size. Such particles can then be effectively removed by conventional ash removing methods. So the acoustic oscillations are actually desirable and experiments with a Rijke tube help decide configurations for which the acoustic energy in these combustors can be maximized [3].

Stirling engine is a device that converts heat energy into mechanical power by alternately compressing and expanding a fixed quantity of air or other gas (the working fluid) at different temperatures [6]. Advantages of Stirling engines:

- They can run directly on any available heat source, not just one produced by combustion, so they can run on heat from solar, geothermal, biological, or waste heat from industrial processes.
- A continuous combustion process can be used to supply heat, so most types of emissions can be reduced.
- Most types of Stirling engines have the bearing and seals on the cool side of the engine, and they require less lubricant and last longer than other reciprocating engine types.
- The engine mechanisms are in some ways simpler than other reciprocating engine types: no valves are needed, and the burner system can be relatively simple.
- They can be built to run quietly and without an air supply, for air-independent propulsion use in submarines.

Disadvantages of Stirling engines:

- A Stirling engine cannot start instantly; it literally needs to "warm up". This is true of all external combustion engines, but the warm up time may be shorter for Stirlings than for others of this type such as steam engines. (Stirling engines are best used as constant speed engines.)
- Power output of a Stirling tends to be constant and to adjust it can sometimes require careful design and additional mechanisms. (This property is less of a drawback in hybrid electric propulsion or "base load" utility generation where constant power output is actually desirable.)

Heating anf refrigeration with thermoacoustic:

The development of a combined electrical generator, refrigerator based on two coupled thermoacoustic Stirling engines, has recently been disclosed. The name is SCORE (Stove for Cooking, Refrigeration and Electricity) [7, 9]. The aims of project are significantly improve health, quality of life, economic growth and social and educational opportunities, and thus reduce poverty in Africa and

Asia by understanding the energy needs of their rural communities and working with them to develop the capability to manufacture an affordable versatile domestic appliance. Malnutrition is one of the two main killers in the developing world, due in part to the difficulties in preparing and storing food. Refrigeration is all but impossible in areas where electrical service is absent or unreliable. Preparing food can also cause problems, especially with overuse of local resources [8]. This device will combine the functionalities of a high-efficiency cooking stove, an electricity generator and a refrigerator (cool box), referred to as SCORE, and may be fuelled by burning a range of biomass products. The operation of the electricity generating and refrigerator parts of the proposed device will be based on a novel application of thermoacoustic processes. Fundamentally, these rely on the interaction between an acoustic field and solid boundaries, leading to a range of fluid- and thermo-dynamic processes, which do not require harmful working fluids or moving parts in the traditional sense; the electrical power extraction is accomplished by a linear alternator. The concept of the device is based on the proven thermoacoustic Stirling engines and refrigerators developed by Los Alamos National Laboratory.

University of Utah physicist Orest Symko began a research project in 2005 called Thermal Acoustic Piezo Energy Conversion (TAPEC). Symko and his students are developing much small devices that not only convert heat to sound, but then use the sound to generate electricity (using existing technology "piezoelectric" devices). „*The technology holds promise for changing waste heat into electricity, harnessing solar energy and cooling computers and radars.*” [10]

6. Conclusion

We performed the experiments with the tubes in team work. Basically we used cheap tools, that can be found in every school; those tools that we did not have in our school, we borrowed from somewhere else, so we did not have extra expenditures. One of the most important statements of the Rocard-report is that the expenses of the experiment should be reduced, and also that we should put a higher emphasis on the project work of the students [1]. These were fully realized in our measurement series. Our students can be seen on the picture 8, while completing their tasks.

Picture 8. *Our students performed the experiments with the tubes in team work*

We found a minimum threshold value for the heat power supplied below which no self-sustained acoustic oscillations may be possible. In our experiment, this value was about 130-150 W. When about 300-450 W are supplied to the heater, great acoustic amplitude is observed; we can say that there is an optimal point (an interval) in the power and duration of warming as well, where the sound issued by the tube can be heard for the longest time. There is an ideal position for the mesh as well. In this position ($x=L/4$) the temperature of the grid is lower than in other cases (when the mesh is lower or upper than this position), still, the longest sound will arise here. Sound can be issued by the horizontal Rijke-tube as well, but only when we ensure the separate air current. This air current intensity has an optimal range as well: we did not perceive any sound effect neither in the case of too weak, nor by too powerful air current.

There are many methods to get the students' interest. With those, who were interested in music, we discussed that the Rijke tube was originally made to be a musical instrument. Why did it fail to be a successful musical instrument? With those, who were interested in crime stories, after examinig the acoustic spectrum of the tubes we also examined the spectrum of their voice with the Audacity program. Everyone has a different „voice-markings", so we were able to identify each student based on their voice as they do this in the crime stories based on fingerprints. The most important result of the project was that there is a natural curiosity in every student towards at least one branch of the natural sciences, and the teachers' task is to use this natural interest as a motivating power to reach our goals.

During the measurements always emerged new problems to solve; but these act as motivation force for the students. In our project work has benn actualized the Problem-Based Learning, which describes a learning environment where problems drive the learning: learning begins with a problem to be soluted, and the problem is posed in such a way that children need to gain new knowledge before they can tackle the problem. *"Rather than seeking a single correct answer, children interpret the problem, gather needed information, identify possible solutions, evaluate options and present conclusions."* [1]

We can tell that not only the students' knowledge about thermoacoustics was developing, but also their natural scientific thinking and their ability to recognize and then solve problems. Besides these their social skills were improving as well (team-work, sharing task and sharing tools, etc.), which I think will be very important regarding the future. I really would suggest my colleagues to try these, or similar thermoacoustic experiments, because they are easily work out, still, they can expect a very spectacular result.

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