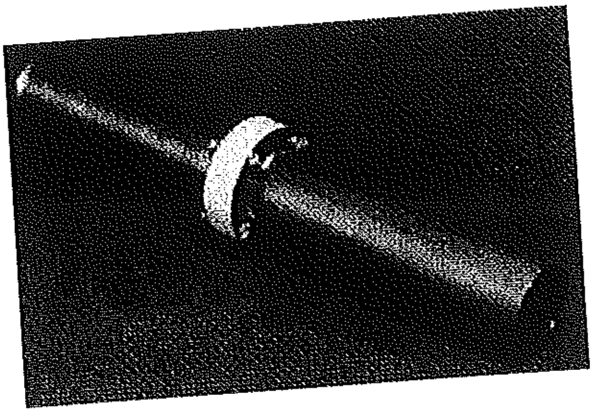
P71-29

What is this?

Thermoacoustic pipe is a thermally driven oscillator. Basically it is a prime mover which accepts heat at room temperature, rejects heat at lower temperature and emits sound.

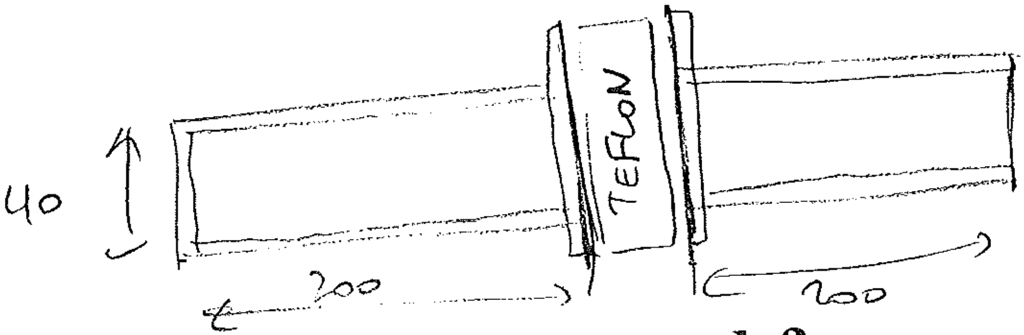


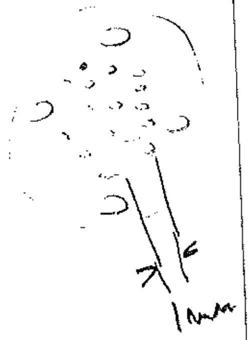
It is very simple: we hold the pipe with the hand (body temperature, around 96°F), cool the other end of the pipe in liquid nitrogen (low temperature, around -321°F) and the pipe 'sings'.

The name of the pipe comes from the effect which makes the pipe emit sound. It is the **thermoacoustic effect** where heat (*thermo-*) is converted into acoustic oscillations - sound (*-acoustic*).

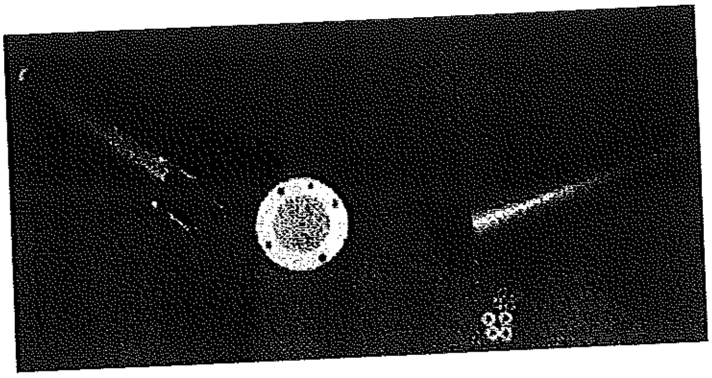
The beauty of the thermoacoustic pipe lies mainly in its simplicity. In everyday life one is used to many different prime movers: internal combustion engines in cars, motor scooters, lawn mowers, steam engines in oldtimer railway engines etc. All mentioned prime movers are pretty complicated mechanisms with parts which rotate, slide and swing during the operation. The thermoacoustic pipe... (here comes the beauty) ...consists only of three parts, which do not move in either way during operation.

You don't believe? Go on! >>

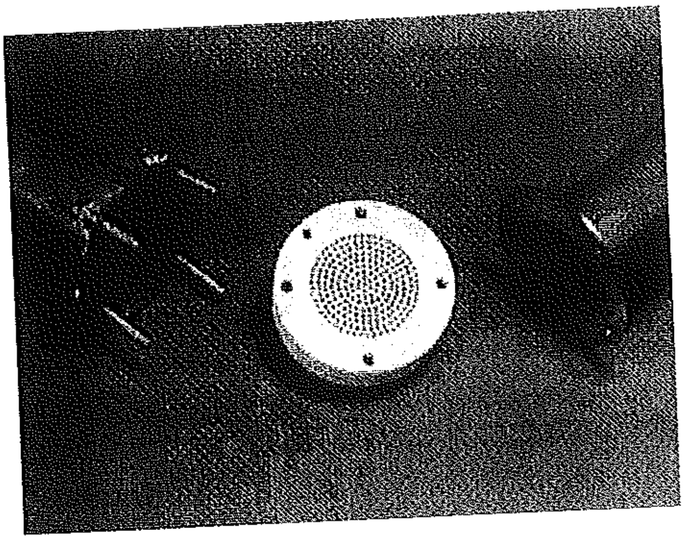




How is it made?



The pipe is made using a copper tube, a piece of copper sheet and a piece of plastic. The right copper piece on the figure consists of an empty copper tube and a round piece of copper sheet soft-soldered together. The end of tube opposite to copper sheet is left open. The copper sheet is densely perforated with small holes (see detail on next figure). The part in the middle is made of plastic and is perforated like the copper sheet mentioned above. The left copper piece is similar to the right one only that its left end is closed with a piece of copper sheet. Small holes bored in all three parts should overlap exactly.



The three parts are put together using four metal screws with paper washers. The pipe is then ready to use.

You can download the design of the pipe in gif format (35 k).

Are you interested in how the pipe sings? Go on! >>

The Experiment

What is this? | How is it made? | The experiment | Why does it sing?

For the experiment you need:

- 1 thermoacoustic pipe and
- 1 suitably large Dewar vessel filled with liquid nitrogen.

> **CAUTION!** Liquid nitrogen requires careful handling due to its low temperature (around -321°F). Danger of freeze burns should be your first concern.
>
> **Read safety instructions!**

The pipe should be dipped in the liquid nitrogen **slowly and carefully** so the fluid doesn't splash. We dip the open end of the pipe and hold the closed end firmly with a bare hand.

Are you ready? Dip the pipe in the liquid nitrogen. >>

The Experiment - shhhh...

What is this? | How is it made? | The experiment | Why does it sing?

Liquid nitrogen boils and sizzles...

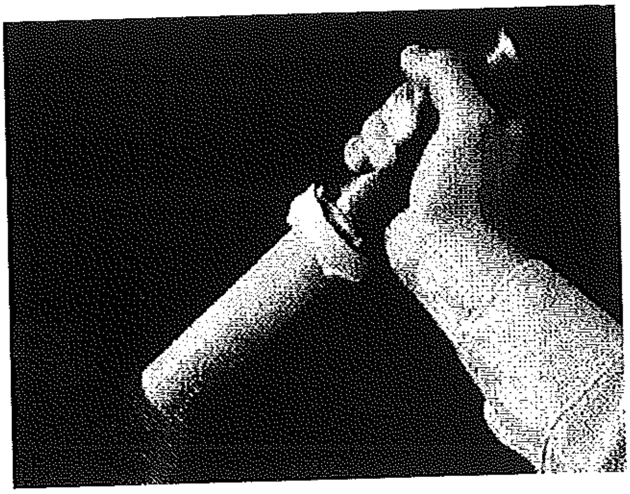
When the open end of the pipe is cold enough we feel the pipe slightly shaking just like a purring cat.

This is the right moment to lift the pipe from the Dewar and...

Listen to the .wav (71 k).

Ready? Lift the pipe from the Dewar. >>

The Experiment - The Sound



The pipe sings!
(Or, more precisely, howls.)

The cold part of the pipe slowly heats up, the sound changes and finally vanishes.

We could dip the pipe in Dewar again and cool its open end.

But let us leave the pipe to heat up to the room temperature and meanwhile try to explain how it can produce sound if nothing moves in it. Any suggestions?

Listen to the .wav (65 k).

How the pipe produces sound? >>

Listen to three **complete recordings:**

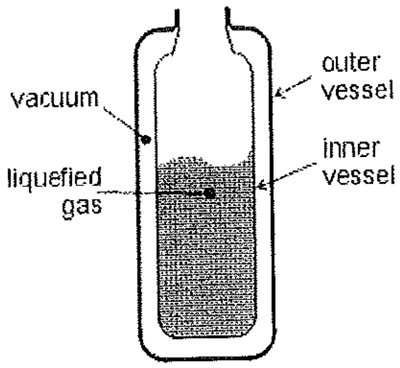
- piscal3-t.wav (775 k) - complete recording (the upper sound is a short part of it),
- piscal1-t.wav (577 k) - another complete recording; the changing of the sound amplitude and pitch can be clearly heard; clicking of the camera is (unfortunately) also heard,
- piscal2-t.wav (810 k) - ...and another complete recording.

Take a look at the **diagrams of the recordings**, their **frequency spectra** and the **changing of the frequency and amplitude** of the sound with time.

Dewar Vessel

Back to The Experiment <<

Dewar vessel is used for storing liquids (liquefied gases) at low temperatures. It is a vessel with double walls, the space between which is evacuated. The vessel was devised to preserve liquefied gases by preventing the transfer of heat from the surroundings to the liquid. The evacuated space between the walls (which are ordinarily glass or steel) is practically a nonconductor of heat. The radiation is reduced to a minimum by silvering the glass or steel. The chief path by which heat can be communicated to the interior of the inner vessel is at the vessel's neck, the only junction of the walls, which therefore is made as small as possible. This thermal isolation applies equally to heat, a hot liquid remaining at a high temperature in the flask for several hours.



Dewar vessel

It is named after the inventor Sir James Dewar (1842-1923). He was British chemist and physicist and invented double walled vacuum flask in the 1890s.

Today Dewar vessel is widely used in low temperature science and applications. It is also well known as a thermos flask for conserving hot liquids (tea, coffee).

Back to The Experiment <<

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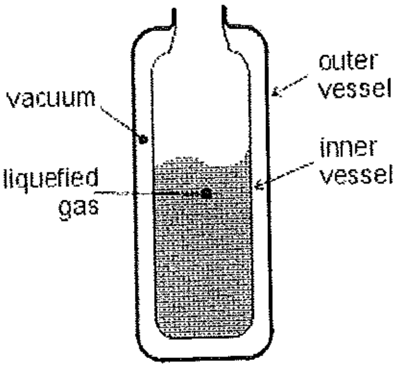

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Back to The Experiment <<

Liquid Nitrogen Demonstrations

Safety Notes & Concerns

Liquid nitrogen is a dangerous material. The following is an excerpt from the Air Products Nitrogen Material Safety Data Sheet:

A back of the envelope calculation indicates that the entire contents of a 10 Liter dewar being spilled in a unventilated 274 square foot room with an 8 foot ceiling would reduce oxygen levels below the 19.5% level where Air Products recommends the use of a respirator. Since most classrooms are larger than this, suffocation does not represent a major danger. When transporting the liquid in a car, however, it is probably a good idea to open a window.

The possibility of freeze burns represents a much more serious danger and is therefore our first concern. This does not mean that the demonstration itself is dangerous, but it does mean **you must be careful**. Dangers include:

- Nitrogen can spatter (possibly in eyes) while being poured.
- Flying chunks of frozen objects could cause eye injury.
- Students (being children) will want to reach out and touch nitrogen or other cold objects. As mentioned above, contact with nitrogen can cause tissue damage, and this must be prevented.

Therefore specific safety precautions should include:

- Teachers must stress to their students the importance of not touching frozen objects or nitrogen.
- Wear goggles whenever pouring or dumping nitrogen. Nitrogen can spatter into the eyes, and potentially blinding pieces of frozen things can fly around when we drop it.
- Use a glove and / or tongs to handle any object going into or out of nitrogen and to carry the nitrogen dewar.

Teachers should familiarize themselves with the following first aid instructions (excerpted from the Air Products Nitrogen Material Safety Data Sheet) for cryogenic freeze burns just in case the worst happens:

If cryogenic liquid or cold boil off contacts a worker's skin or eyes, frozen tissues should be flooded or soaked with tepid water (105-115F, 41-46C). ***DO NOT USE HOT WATER.*** *Cryogenic burns which result in blistering or deeper tissue freezing should be seen promptly by a physician.*

Remember to stress the importance of not touching liquid nitrogen or frozen objects.

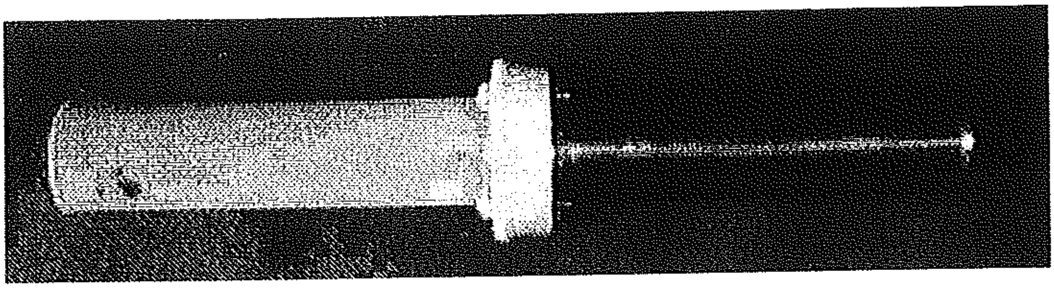
See also Liquid Nitrogen Safetygram (in pdf format - see below) from Air Products and Chemicals, Inc.

Note: **the Liquid Nitrogen Safetygram above requires Adobe Acrobat Reader** which is available for free download.

Get Acrobat Reader Download Adobe Acrobat Reader

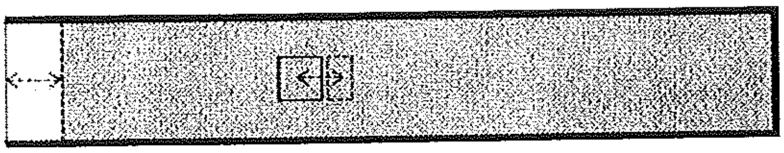
·Liquid Nitrogen Page
·Science Alliance Demos Page
·Science Alliance Home Page
·Fairmount Center for Science and Mathematics Education Home Page

How the Pipe Produces Sound?



Let the pipe heat up and let us look at its mystery.

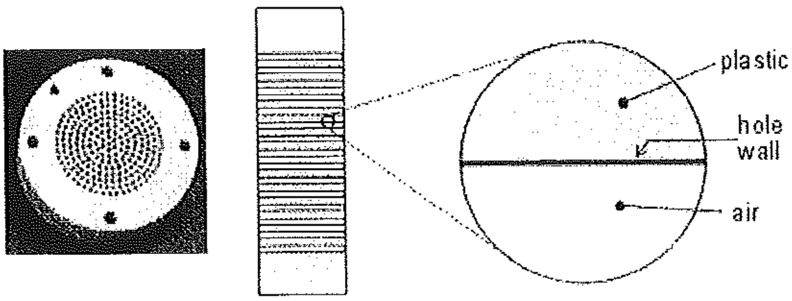
Basically, the thermoacoustic pipe is a tube which is closed on one end. Suppose that the air in it oscillates at the fundamental frequency like in the simple tube closed at one end. This is an approximation since the thermoacoustic pipe is not an empty tube and the temperature along the pipe is not constant. The air in the empty tube is compressed toward the closed end and expanded toward the opening while the tube 'sings'. So the air in the tube oscillates along the tube and is compressed while moving toward the closed end and expanded while moving toward the open end.



Click on the figure to see animation. (51 k)

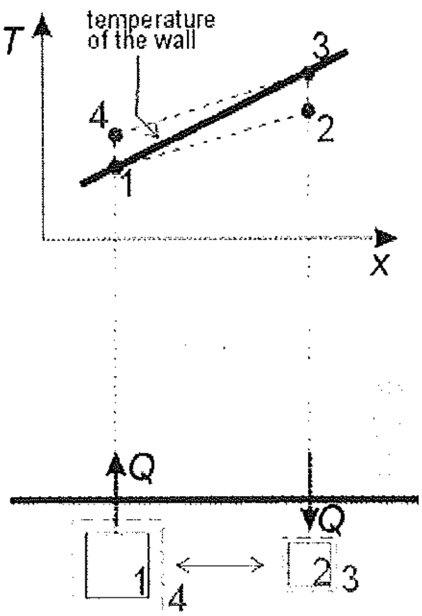
Let us orientate the thermoacoustic pipe with the closed end to the right like the tube on the upper figure. Any chosen volume of air in the pipe is then compressed while moving to the right and expanded while moving to the left. Because the movements are swift (the frequency of the oscillation is 200 Hz in our case) the compression and expansion are adiabatic. So the air heats up (red color on the figure) while being compressed and cools while being expanded.

The plastic part of the pipe is densely perforated with small holes. Let us limit ourselves to only one little hole and look closely at what is going on in a region close to the hole wall.



Temperature of the wall changes along the hole. The right end of the plastic part is warmer than the left one because the right end is joined with the copper part of the pipe we hold in our hand while the left end is joined with the copper part cooled in liquid nitrogen. We shall assume that the temperature of the plastic wall rises linearly to the right.

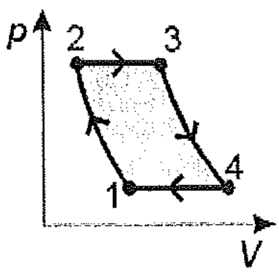
Let us choose a small volume of air close to the hole wall and follow its path along the wall. The chosen volume should be large enough so that its thermodinamical description is valid. Let us name the chosen volume of gas **'a parcel of gas'**.



The figure on the right shows the wall temperature depending on the x coordinate along the hole. We limit ourselves to the region of coordinate x in which our gas parcel oscillates.

We start with our parcel at the point 1. Its temperature is equal to the temperature of the adjacent wall. For the sake of simplicity we shall replace parcel's sinusoidal motion with the rectangular one: rapid motion - wait - rapid motion - wait - etc. So the parcel rapidly moves to the point 2. Its temperature increased because during the movement it compressed adiabatically. Still its temperature is lower than that of the adjacent wall (look at the temperature diagram) and during the wait period the parcel accepts heat Q from the wall. Parcel's temperature rises until it equals the temperature of the wall (point 3). During the isobaric heating (2-3) parcel expands as indicated on the figure. In the next step the parcel rapidly moves back to the starting point (4). Because it accepted heat in step 2-3, its temperature is higher than that of the adjacent wall. Therefore the parcel gives heat Q to the wall and cools to the temperature of the adjacent wall (point 1). Parcel's volume is reduced due to isobaric cooling.

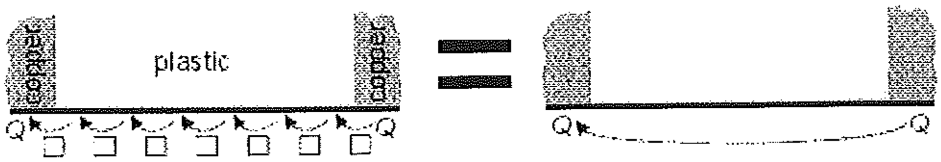
In the cycle described above, the parcel carried heat Q from the hole wall with the higher temperature to the wall with the lower temperature.



The thermodynamic cycle of the parcel is described with two adiabatic curves (1-2 and 3-4) and two isobaric curves (2-3 and 4-1). The area the cycle encloses in the pressure-volume diagram equals the work released in the cycle. In our case the work is done on the parcel.

During the time of one cycle, the parcel **carries heat** Q from a place with higher temperature to the place with lower temperature and **receives work** (work is done on the parcel).

The same holds for all parcels which are suitably close to the hole wall in the plastic part of the pipe. They receive work and transport heat to the left. We could imagine that the heat Q a parcel transported in a cycle is carried forth by his neighbouring parcel in next cycle. In one cycle they altogether carry heat Q from the right (warm) copper part to the left (cold) copper part. Heat transport stops in a copper section beacause the temperature of the copper does not change along the coordinate x due to copper's big thermal conductivity.



The work the parcels receive manifests as an increase of the acuostic energy of the pipe. As the pipe 'sings' the acoustic energy is radiated away. The pipe would quickly stop emitting sound if the energy wouldn't be replaced. The lost energy is replaced by the work the parcels receive.

Termoacoustic effect takes place in a fluid (in our case air) which oscillates like a gas in a simple tube at its fundamental frequency and suitably close to the wall, the temperature of which changes along the path of the oscillating fluid (it rises in the direction of motion of the fluid as its pressure increases). The fluid carries heat from the hotter part of the wall to the colder part of the wall and the acoustic energy of the fluid increases.

Now we can explain why the middle part of the pipe is made of plastics and the other two of copper. We already explained the importance of changing temperature along the plastic part. We obtain it dipping the open copper part of the pipe in liquid nitrogen and holding the other copper part with a bare hand. The temperature of the open end is very low and constant throughout the copper part due to copper's big thermal conductivity. The other copper part is kept warm with the hand. The plastic part is in touch with the cold copper part on the left and the warm copper part on the right. Because plastics is rather poor thermal conductor the part's left side is cold and its temperature increases to the warm right side. That is how we obtain one of the above conditions for the existence of the thermoacoustic effect.

But how can we obtain the required oscillation of the fluid? If the air in the pipe would be completely still nothing interesting would happen. Heat would slowly flow through the plastic part and the temperatures of the copper parts would equalize after some time. But the air is never completely still. Normally, there is a lot of noise coming from traffic, computers in operation, opening and closing doors, talking, etc. The pipe being an acoustical resonator picks up its frequency out of the existing noise. As soon the air in the pipe begins to oscillate the thermoacoustic effect amplifies the oscillations and the pipe begins to 'sing'.

When does the pipe stop emitting sound? The oscillating air in the plastic part transports heat and therefore actively heats up the cold copper part of the pipe. The temperature of the warm copper part is kept constant using the hand as a thermal reservoir. The slope of the wall temperature on the diagram above is therefore less and less steep. The point 4 moves toward the point 1 and the point 3 towards the point 2. When they come together the work received by the air drops to zero (compare with the pV diagram) and the pipe stops singing. The heat flowing through the plastics is considered as a loss and shortens the time of sound emission.

Now you can try to answer some interesting questions:

- Would the pipe sing differently if the middle part was made of stainless steel instead of plastics?
- Why do we use paper washers?
- How would we obtain louder sound?
- What would happen if we would cool the closed part and hold the open part of the pipe? Would the pipe sing?
- What if we would hold the open part and heat the closed part of the pipe? (Assume the pipe is heat resistant.)
- What is the difference between the thermodynamical cycles of the parcels very close to the wall, far away from the wall and the parcels between them?
- Why does the frequency and amplitude of the emitted sound change with time?

Let me recommend you an article with wich you will be able to answer all the above questions except... Well, can you think of a good answer to the last question?

Easy to understand article with beautiful pictures:
G.W. Swift: **Thermoacoustic engines and refrigerators**, Physics Today, July 1995, 22,

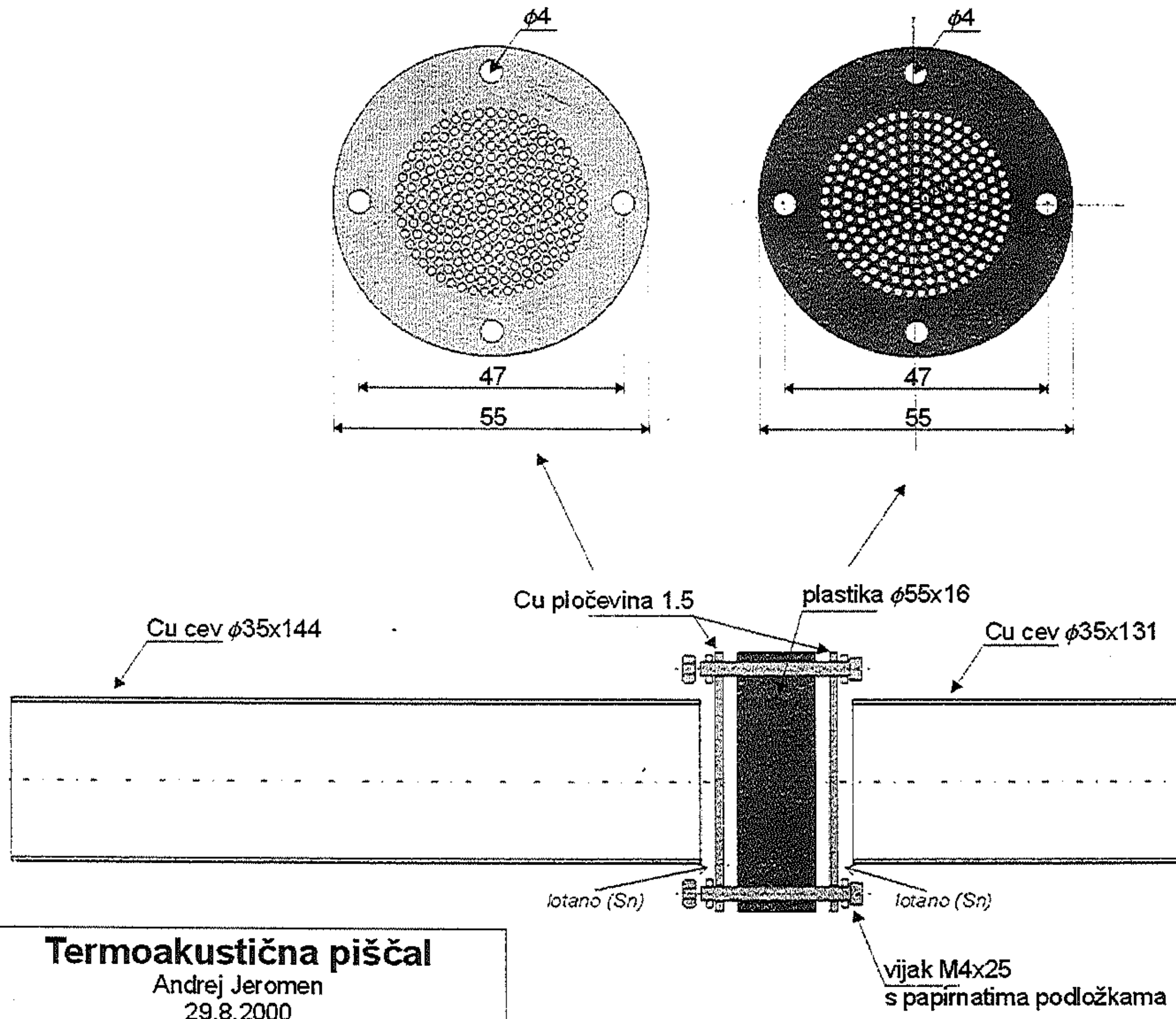
Very thorough work on thermoacoustic engines:

G.W. Swift: **Thermoacoustic engines**, J. Acoust. Soc. Am. **84** (1988) 1145,

The pipe presented has been made after:
J. Wheatley, T. Hofler, G.W. Swift, A. Migliori: **Understanding some simple phenomena in thermoacoustics with applications to acoustical heat engines**, Am. J. Phys. **53** (1985) 147.

The House of Experiments - hands-on science center in Ljubljana

P 2930



Luknje ϕ1.5:
(premer kroga .. število lukenj)
ϕ0..1 → R0
ϕ4..6 → R2
ϕ8..12 → R4
ϕ12..18 → R6
ϕ16..25 → R8
ϕ20..31 → R10
ϕ24..37 → R12
ϕ28..43 → R14
ϕ32..50 → R16

223 trous de ϕ1

PTFE : ϕ80 ep 10mm
Cu d60 ep=20mm

Termoakustična piščal
Andrej Jeromen
29.8.2000
po članku: J. Wheatley, T. Hofler, G.W. Swift, A. Migliori, *Understanding some simple phenomena in thermoacoustics with applications to acoustical heat engines*, Am. J. Phys. **53** (1985) 147