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VORTEX TUBE COOLING SYSTEM

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ABSTRACT

Vortex tube is a device which does not have any moving part and having high development potential in emerging area of energy. Vortex tube is smile energy separating device which separate compressed air into hot and cold stream. The compressed air is tangentially injected to the tube through the nozzle to developed swirl motion in the tube. The RHVT (Ranque-Hilsch Vortex Tube) has been used for many decades in various engineering applications. Because of its compact design and little maintenance requirements, it is very popular in heating and cooling processes. Despite its simple geometry, the mechanism that produces the temperature separation inside the tube is fairly complicated. A number of observations and theories have been explored by different investigators concerning this phenomenon.

Vortex tube of different geometrical parameter gives optimum performance at different cold fraction. This paper gives experiment result of energy separation in vortex tube for different tube diameter and length keeping all other parameter constant .it is observed that tube diameter and length with double inlet nozzle greatly influence on the cooling efficiency and energy separation. The performance of vortex tube depends on various geometric parameters, operating parameters. An in-house facility is to be developed to carry out the experimental investigation on the vortex tube using working substance as air, Vortex tubes of five different configurations are to be developed. The project focuses on the effect of length and diameter of tube that is L/D ratio of vortex tube to optimize the geometrical parameters and comparison with previous different parameter vortex tube.

Keywords: Vortex Tube, Cold-end orifice, Hot end control valve, cold mass fraction, secondary circulation, pressure gradient.

I INTRODUCTION

Environmental problems such as ozone depletion and global warming caused due to CFC refrigerants have compelled us to look for other non-conventional systems. Vortex tube is one of the non-conventional systems where natural substance such as air is used as working medium to achieve refrigeration. Vortex tube has been used for many decades in various engineering applications, which is an interesting experimental object with high development potential in the emerging area of energy and refrigeration engineering. Due to unique combination of technological and operational properties, commercial aspect of vortex tube is widening day by day, because of its compact design and little maintenance requirements; it is very popular in heating and cooling processes.

The Vortex Tube is an effective and economical solution to a wide variety of industrial spot cooling and process cooling needs. Vortex tube is a device which produces cooling at one end and heating at the other end simultaneously. The general name of vortex tube is cooling tube also, which instantaneously create streams of high and low temperature with respect to the temperature of the air which is used as a feed. The highly compressed air is forcing through a swirl generation chamber, and by the virtue of high pressure and limited volume the pressure head of feeding air is get converted into the kinetic head which generates the centrifugal spin of air along the inner walls of the tube. Due to peripheral attachment of nozzle air from nozzle set swirling motion which is responsible to generate vortex. A percentage of the hot, high-speed air is permitted to exit at the control valve. The remainder air is force back from conical valve which is fitted at end of hot end, that air gives heat to outer layer and through the orifice it leaves through cold end. The air leaving the tube near the tube wall will be warmer and that leaving the tube from the Centre will be cooler.

For the performance analysis of vortex tube being made on the basis of some series of different-different constructional features and the performance of tube depends upon:Air parameter and tube parameter. The cold mass fraction produced by tube and temperature is control by adjusting the conical valve at hot end.

1.1 Problem Definition

The single nozzle vortex tube was unable to produce more spinning in the vortex chamber tends to lower energy separation as compared to double inlet nozzle. To increase the performance of tube, it is essential to increase the swirling motion, so it is completed by double nozzle. The performance of vortex tube is increased by changing geometrical parameter. For making tube feasible for application like cooling of electronic equipment, the tube with different L/D ratio required to test for maximum cooling by varying geometrical parameter.

1.2 Methodology

Methodology for vortex tube is as follows:

1. The performance assessment of double nozzle vortex tube using air as substance, five different configuration vortex tubes designed, manufactured and tested.
2. Each vortex tube is tested at various operating condition with air as working substance.
3. A series of experiments are performed to evaluate the performance of the system. In Experiments three tube of same diameter are tested and then three tube of same length are tested keeping all parameter constant.
4. An experimental study conducted to evaluate the effect of working parameters such as inlet air pressure (P), length of tube (L) and diameter of tube (D) on the performance of Ranque-Hilsch vortex tube.
5. Five tubes are tested at various pressures in increment of 1 bar.
6. Different parameters were evaluated like temperature reduction on cold side, temperature rise on hot side, Cold mass fraction (μc) refrigerating effect and COP.
7. Compare the performance of vortex tube with different diameter & length and to find out best parameter set for cooling effect.

II. LITERATURE REVIEW

2.1 Introduction to Literature Review

Research works done by various researchers by concentrating theoretical, numerical and experimental studies. Many CFD studies reported in literature on flow simulation of vortex tube. Some of them also focused on design aspects and working fluids. However, experimental studies are relatively less available in open literature. Subsequent section of this chapter presents a report of the past research on various aspects of vortex tube.

2.2 Literature Survey

Shankar and Anish [2] have performed experiment to study performance of vortex tube by changing valve opening. An attempt has made to study the effect of parameter like nozzle area of inlet compress air. The design of nozzle affects the conversion of pressure to velocity. It doesn't have much contribution in the energy separation process. It is observed that maximum cooling effect obtained at 16.5 mm of hot plug diameter, 90% of Tube inner diameter. CFD analysis shows an 86 % diameter gives maximum cooling effect.

N. Agrawal et al. [3] investigated experimentally on vortex tube using natural substances. The influenced parameter such as L/D ratio, cold mass fraction, inlet pressure etc. is investigated. They determine cold mass fraction at which vortex tube performs optimally. The maximum cold temperature obtained at 60% cold mass fraction. The vortex tube of L/D ratio 17.5 perform optimally out of set of three tubes, other tube have ratio 12.5 and 22.5. Maximum cold end temperature obtained 29 °C with 0.118 COP.

Mohammad Mahmudur et al. [4] constructed design and testes vortex tube for cooling system. Material selected for tube was PVC. The diameter of tube and diameter of inlet nozzle are varied and checked performance of tube. The vortex tube with two inlet nozzle and cold tube diameter 12.7mm yielded the highest temperature reduction, it was observed that 4° C.Inlet pressure was varied from 2 to 5 bar. They got very small temperature difference between inlet air and cold air for single nozzle and for double nozzle 3°C temperature drop found at cold side. The vortex tube with single nozzle gives ΔT_c of 2° C, at pressure of 4 bar. By attaching another nozzle for same parameter temperature difference of 1°C to 3°C obtained in pressure range of 2 to 5 bar.

A.S.Gavade et al. [5] Performed experimental study on operating parameter on counter flow vortex tube, the material used for tube was brass because of its conductivity and low friction. The tube was tested in pressure range of 2 – 8 bars. The air was supplies through single tangential inlet nozzle. The L/D ratio taken was 12.5, 13.5, and 17.5 with tube diameter of 10mm used. Nozzle diameter of 2 mm kept constant and orifice diameter 3, 4 and 5 mm are used in experiment. The maximum temperature difference of 14 °C obtained on cold side and 17°C on hot side, COP of 1.12 obtained at 17.5 L/D ratio. The optimum value of L/D ratio determined experimentally was 17.5, at this ratio ΔT_c and ΔT_h was maximum with 0.65 cold mass fractions.

Omkar kubade et al. [6] performed an experimental study on counter flow vortex tube with air as working fluid. The pressure of air varied from 2 – 6 bar. Keeping L/D ratio constant air entered at tube with two nozzles and the material selected for tube was aluminium, mild steel, and brass. The cold temperature difference of 20°C obtained at 10 bar inlet pressure with cold mass fraction varying from 0.2 to 0.6.

S.Kasim et al. [7] investigated to determined maximum COP of vortex tube, for given pressure. The temperature difference of conical hot tube was better than cylindrical hot tube and the temperature difference between them was proportional to pressure. To get these COP, the nozzle and orifice diameter was kept unchanged and highest COP was obtain at 6 bar pressure for taper tube is 0.1540.

Mahyer et al. [8] investigated experimentally the effect of orifice diameter and length of tube on vortex tube. They calculated cooling and heating capacity of vortex tube. The tube having cone nozzle diameter 8mm with conical valve angle of 50° . The diameter of tube kept constant that is 25mm and length is varied from 250mm, 519mm, and 769 mm. The cold orifice varies from 8mm to 125 mm. They found 8mm diameter orifice gives satisfied results with 519 mm length tube. Also some tube creates highest temperature of 9°C on hot side and maximum cold side temperature difference of 10 °C Produced by 769mm length tube. This maximum temperature difference obtained when cold mass fraction within range of 60 to 70 %. The L/D of 30.76 gives best result during experimentation.

S.Raut et al. [9] conducted experiment to execute the behavior of vortex tube refrigeration system. The effect of L/D ratio, cold mass fraction and inlet pressure difference was studied and found 22°C is maximum temperature difference obtained on cold end side.

Ratnesh shau et al. [10] calculated COP of vortex tube in the exploration of temperature separation in vortex tube, different factor consider such as pressure gradient, flow. The calculations done with knob fully close and then partially open and result is tabulated. When Knob was fully closed, Maximum COP of 0.06 obtained at Temperature difference of 14° c.The cold side Temperature difference of 13.7 °C is obtained at Pressure range of 3.5 to 10 bar. Then readings are taken by opening the knob at hot side by 20% then maximum COP obtained 0.05 at Temperature difference of 14.7 in same Pressure range.

S.Rejin and H. thilkan [11] found performance of vortex tube refrigeration system by considering the effect of conical valve angle. A six type of conical valve were used tested for individual cold orifice. The procedure is repeated for four set of cold orifice and six set of conical valve angle; during whole experiment mass flow rate and temperature of inlet, cold and hot air were noted and was tabulated. The author decrease the cone angle from 45° to 10° without altering the inlet conditions found temperature difference of 3.5°C. Compressed air at pressure of 5bar was introduced at the inlet .For this given inlet conditions a maximum temperature reduction of 7°C was achieved. Maximum temperature reduction of 24°C was obtained at 10 ° valve angle.

A.M.Dalavi et al. [12] used new geometry of helical convergent nozzle in which helical nozzle converge from 8mm to 3mm diameter and allowed to escape to vortex diameter 12.5mm tangentially. Modification is done for pre whirl the air during inlet and also to increases the swirl intensity of the air. Different parameters were experimentally tested at different pressure i.e.2 bar, 3bar, 4bar, 5bar. The maximum COP obtained was 0.376. also at 5bar Pressure and 45° and 90° valve angle gives Best results.

Rahul pise and Avinash patil [13] did the comparative study of conventional vortex tube and modified tube. The modified tube having new nozzle with equal gradient of Mach number and flow velocity were designed and developed to reduce the flow losses and new kind of diffuser invented to reduce friction losses. The cooling effect of the conventional is lower by 5°C with pressure range of 0 to 1.6 Mpa.

Jaykumar D. Golhar et al. [14] performed experiment to find the effect of nozzle diameter and investigate optimise vortex tube, keeping all parameter constant. After the experimentation on the vortex tube with different nozzle diameters, it can be concluded that, nozzle diameter have great influence on the performance of vortex tubes. Cold temperature drop varies with the variation of nozzle diameter. But there is a unique nozzle diameter that gives the optimum performance for various geometrical parameters. The pressure of inlet air, Pi was varied from 1.0 bar to 2.5 bar with the increment of 0.5 bar. The tube length, L was varied from 250 mm to 500 mm with the increment of 50 mm. The nozzle angle was varied from 1.50 to 4.00 with the increment of 0.50. The nozzle diameter, Din was varied from 2.8 mm to 3.8 mm with the increment of 0.2 mm. The optimum value of nozzle diameter (Dn) for maximum cold temperature drop (ΔTc) max was 3.2 mm.

J. prabhakaran and S.Vidyanathan [15] investigated for effect of orifice and pressure of counter flow vortex tube, as the inlet pressure increases, temperature difference increases. At low pressure (4 bar) entire orifice has better performance but at higher pressure orifice with 6mm diameter perform well. The diameter of orifice influences the expansion that take place in vortex tube. Maximum Temperature drop of 20°C was observed at 5 bar pressure.

Kartik S. [16] determine temperature distribution of rotating air using different material for tube such as stainless steel, brass tube etc. out of these stainless steel is more efficient.

By controlling the opening of the valve, the proportion of cold air and hot air and their temperatures can be varied. Some of the restrictions followed were:-

1. For obtaining the maximum temperature difference at cold end, the ratio L/D should be maintained in the range of $30 \leq L/D \leq 60$. Hence, considering the length to be 113.03cm and diameter to be 2.05cm, we get the L/D ratio to be in the range.

2. Decreasing conical valve angle have positive effect on performance of vortex tube but not so much difference is observed in the temperature reduction. Therefore it is better to use conical valve with smaller angle in order to improve the performance of vortex tube.

Nellis et al. [17] presented a semi-empirical model of the vortex tube using one hypothesis regarding its underlying physics. The vortex tube model is integrated into a model of a vapor compression refrigerator and a Joule-Thomson cryogenic refrigerator. The potential for increasing the performance of a refrigeration cycle using the vortex tube is found to be extremely limited for the vapor compression cycle. However, it is shown that the vortex tube may present a significant opportunity to improve the performance of refrigeration systems using the Joule-Thomson cycle and may allow efficient operation at lower pressure ratios, with smaller recuperative heat exchangers, and with less expensive working fluids than are currently used. More complex cycles are discussed in which the vortex tube can be used to simultaneously perform phase and energy separation.

Rajarshikar et al. [18] found the effect of feed gas temperature on the Ranque-Hilsch vortex tube. It is observed that increase in feed gas temperature change temperature i.e. cold flow temperature decreases and again with increase in feed gas temperature change in temperature decreases (hot flow temp. difference). It also confirms that with increases of μc, hot end temperature increases continuously and cold end temperature increase continuously. With the increase of μc, ΔTc decreases but below room temperature it decreases in another fashion which is perhaps due to the inaccuracy of temperature measurements. Also ΔTh value increase with increase of μc. the value of μc for which minimum temperature of the cold flow can be obtained is about 0.2. The value of μc for which maximum temperature of the cold flow can be obtained is about 0.8.

Saidi and Valipour [19] presented information data on the classification of the parameters affecting vortex tube operation. In their study, the thermo physical parameters such as inlet gas pressure, type of gas and cold gas mass ratio, moisture of inlet gas, and the geometrical parameters, i.e., diameter and length of main tube diameter of the outlet orifice and shape of the entrance nozzle were designated and studied. The L/D ratio was maintained between 20 To 55.5 and at 3 bar pressure cold orifice diameter Dc= 0.5 mm gives best results.

Xue and Arjomandi [20] found the effect of the vortex angle on the performance of the RHVT system. A new structure, the vortex angle generator, was used to form different vortex angles. Different angles were set in the test in order to find the effect of the vortex angle. The vortex angle played an important role in both the separation of cold and hot flows and the vortex tube performance. A smaller vortex angle demonstrated a larger temperature difference and better performance for the heating efficiency of the vortex tube. However, small vortex angles resulted in better cooling efficiency only at lower values of input pressure. The existence of the peak value on the cooling efficiency of the RHVT system has not been resolved clearly in this research and more investigation with low pressure injected air is needed. Vortex angle ranging from 2.5 to 23 ^{o} are checked at pressure range of 2 to 5 bar that time cold mass fraction varies from 0.55 to 0.69 and cold air temperature 16°C was observed 2 bar pressure. The cooling efficiency of 0.18 get at 4 bar Pressure.

Eiamsa-ard et al. [21] performed the effect of the snails with the inlet nozzle number of 1,2, 3 and 4 nozzles offer higher temperature separation and cooling efficiency in the RHVT as compared to the conventional tangential inlet nozzles (4 nozzles). This is0 because the use of the snail instead of the conventional tangential inlet nozzles can reduce pressure loss and thus provides stronger vortex/swirling flow in the RHVT. The obtained results suggest that to achieve higher cold air temperature reduction and cooling efficiency, the cold mass fraction should be adjusted to be around 30 to 40%. As such a condition, the mixing of the hot air and the cold air within the RHVT can be suppressed.

Markal et al. [22] conducted an experimental study to investigate effects of the conical valve angle on thermal energy separation in a counter-flow vortex tube. A new geometry is designed for the cold end side, which is called “helical swirl flow generator”. Combined and interactive effects of the helical length of the swirl flow generator, the ratio of the tube length to the tube inner diameter (L/D), the inlet pressure and especially the angle of the conical valve on the performance of the vortex tube are comparatively investigated as a function of the cold mass fraction μc. Four different conical valves have been used with the angle of 30°, 45°, 60°and 75° and observed that it’s better to use the conical valves with a smaller angle in order to improve the performance of the vortex tubes.

2.3 Gaps in Literature

- Most research work was carried out for vortex tube with brass, stainless steel, and mild steel with single nozzle vortex tube. This research work would focus on performance with double nozzle with PVC material of tube.
- In literature the tube with constant length and varying diameter are investigated. This project will investigate comparison of performance of tube, keeping diameter constant and then keeping length constant.

2.4 Conclusions from Literature Review

1. An efficient tube design should be many times longer than its diameter and Optimum L/D is a function of geometrical and operating parameters.
2. L/D has no effect on performance beyond L/D > 45.

3. For obtaining the maximum temperature difference at cold end, the ratio L/D should be maintained in the range of $30 \leq L/D \leq 60$.
4. Smaller diameter vortex tubes provide more temperature separation than larger diameter ones. A very small diameter vortex tube leads to low diffusion of kinetic energy which also means low temperature separation.
5. Maximum refrigeration occurs when a RHVT operates at 60–70% cold fraction. Minimum cold temperature occurs when a RHVT operates at 30% cold fraction.
6. Using materials with lower thermal conductivities and more smooth surfaces results in better temperature separation and performance.
7. The roughness of the inner surface of the tube has influence on its performance.
8. The Optimum value for the angle of the hot side valve is approximately 50° .
9. A very small optimal conical angle (3°) exits in divergent vortex tube.
10. The tube having cone nozzle diameter 8mm to produced maximum cooling effect.

III. DESIGN AND DEVELOPMENT OF VORTEX TUBEZ

3.1 Material Selection:

By considering all parameter, a vortex tube of size 21 mm inner diameter of CPVC was selected. The vortex tube has three Different lengths 300mm, 350mm and 400 mm. Two straight nozzles were made and each had 4.2 mm diameter. Similarly, cold orifices were used having hole diameters of 5 mm. A conical valve made of brass was provided on the right hand side of the tube to regulate the flow. Materials were selected based on easy availability, ease of working, and insulating capability which is necessary for achieving Properties of UPVC material-

i. Thermal Conductivity- 0.13 W/mK

ii. Specific heat – 0.025 Kcal/Kg°C

iii. Density- 1.43 g/cm3

iv. Softening point - 80°C

The geometrical design parameters used in the experimentation are listed below in two tables. Table 3.2 consists of design parameters when length of tube is constant and diameter varied

3.2 Tube Geometry

Diameter of cold end orifice, Dc = 5mm is selected.

Table 3.2 Constant length (L=400 mm) and varying the tube diameter

Sr.No.	Length of tube (mm)	Diameter of tube (mm)	L/D ratio	Diameter of cold orifice (mm)	Diameter of inlet nozzle (mm)	Cone angle of hot valve	Number of nozzle
Tube 1	400	21	19.04	5	4.2	45°	2
Tube 2	400	15	26.66	5	4.2	45°	2
Tube 3	400	12	33.33	5	4.2	45°	2

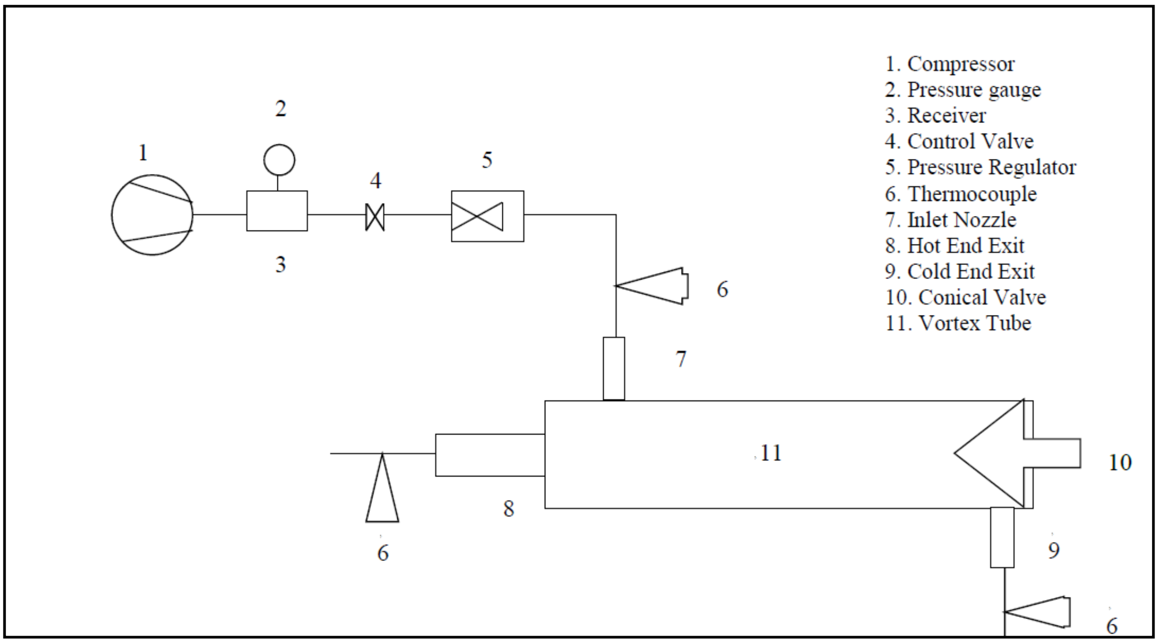

Figure 3.2 Schematic diagram of experimental setup

3.3 Observation Table :

Observation table are made for tube 2

Pressure (Bar)	Cold Flow Rate (mc) M/sec	Inlet Temp (Ti) º c	Cold End Temp (Tc) º c	(ΔTc) º c	Hot End Temp. (Th) º c	(ΔTh) º c	Water column Height Difference (Hw)mm	Number of Revolution Of energy meter	Time in min
1	2.7	31	25	5	35	4	18	9	8
2	2.6	31	22	9	33	2	18	13	6
3	2.9	30	20	10	32	2	19	15	6.16
4	2.8	32	21	11	40	8	18	20	5.33
5	2.5	33	15	18	43	10	18	21	4.14
6	2.2	32	15.1	16.9	43.8	11.8	18	26	3.53
7	1.53	33	15.1	17.9	44.5	11.5	16	32	2.23

IV. CONCLUSIONS

Performance evaluation of the counter flow vortex tube with double nozzle carried out experimentally.

1. For a given L/D ratio, as the air pressure increases, cold end temperature difference increases but the optimum value of cold mass fraction remains same.

2. The cold mass fraction 0.76 at which vortex tube performs optimally at the pressure of 5 bar and L/D ratio 26.66.

3. The maximum cold temperature drop 15°C obtained at cold mass fraction/ratio of 76% by tube 2 (L/D=26.66). It is also observed that the cooling effect produced by the vortex tube depends on properties of the gas, molecular weight and specific heat ratio The Cold temperature difference (ΔTc) is maximum that is 18°C for the pressure of 5 bar which gives best performance. The temperature drop increases with increase in inlet pressure.

4. Maximum hot temperature of 44.5°C produced by tube having L/D 33.33 and 26.66.

5. It is found that the vortex tube of L/D ratio 26.66 performs optimally. In the tested range, COP and cooling capacity both shows increasing trend with cold mass fraction up to cold mass fraction of 60%.. COP of tube decreases with increase in pressure, maximum cop obtain 0.81 for tube 2.

6. The optimum value of L/D ratio is in range of 16-26 as in this range ΔTc and ΔTh is maximum. The highest temperature drop is found between 0.5-0.7 cold air mass fractions.

7. In set of different tube diameter 12mm, 15mm and 21mm the tube with 15mm diameter gives best output. In set of different length 300mm, 350mm, and 400mm the tube with length 400 mm gives best performance.

V. FUTURE SCOPE

Other natural working fluids apart from air need to be tested using double inlet nozzle. The proposed project work involves the performance evaluation of vortex tube with double inlet nozzle, using air at pressure; their comparison.

The current phase of project described here done by manufacturing the vortex tube with the easily available resources, from the study done so far on vortex tube we already know that its C.O.P. is very less and we wanted to study it practically. Vortex tube also involves second law of thermodynamics which shows the degradation of energy from a higher quality and quantity to lower quality and quantity. The study is successfully made by using a separate compressor. This compressed air for the practical application should be taken from other resources where it is going waste. Utilizing waste is always a warming issue for the industries. We hope that this study will play an important role in the future scope of this project.

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