Research the Acoustic Cloth Drying Process in Mock-Up of Drum-Type Washing Machine

Vladimir N. Khmeln, IEEE Senior Member, Igor I. Savin, IEEE Member, Denis S. Abramenko, IEEE Student Member, Sergey N. Tsyganok, Roman V. Barsukov, Andrey N. Lebedev.
Biysk Technological Institute (branch) of Altay State Technical University named after I.I. Polzunov, Biysk, Russia

Abstract - This article shows result of researches, aimed to increasing the efficiency and productiveness of “classic” cloth convective drying method in drum-type washing machine with simultaneous decreasing the power consumption by means of include the high-power acoustic radiator into washing machine design.

I. INTRODUCTION

Drying is a final stage of any cloth washing, consisting at moving off moisture from cloths, presented the most prolonged and the most charges.

Now in drum-type washing machine the most distribution was received convective modes of cloth drying [1, 2]. It is implemented as follows: dry air is heated by a built-in heater. Then by the fan it is guided on the air channel to a drum for cloth. Passing through cloth, air it is moistening, taking away moisture from cloth. Whereupon enter in the condenser where it is cooling as a result the moisture is condensed. Dry air again is heated and guided to a drum for cloth. Process repeating for removal of necessary quantity of moisture from cloth.

The convective mode of drying has an essential limitation:
- Drying process requires extremely quantity of energy and has large duration;
- In case of small-sized (narrow) washing machine, the air volume in a drum is decrease, that restricts a speed;
- For acceptable quality of drying it is necessary to reduce loading, or to dry the washed cloth in two steps;
- The long high-temperature nonuniform power influence is destroy synthetic materials and lead to drying up and damage of cloth.

Introduced limitation is make conditional upon the key a limitation put its basis

Therefore realization of cloth drying with use of high intensity acoustic oscillations is perspective.

It is known [3], that the humidity of a dryable material from time of drying process (at constant power influence) is characterized by the composite nonlinear dependence. It is possible to allocate two phases of drying process. During the first phase the speed of drying is constant. In accordance with decrease of humidity of dryable material, there occurs the moment when a speed of drying asymptotically tend to zero.

High intensity acoustic influence allows intensifying both phases of drying process [4]. During the first phase of drying acoustic oscillations allow to reduce width of a hydrodynamic boundary layer. In an acoustic field the hydrodynamic boundary layer can be much less diffusion. It signifies that acoustic oscillations will penetrate inside of a diffused layer, create turbulence, and thus speed up evaporation process.

The acoustic drying method has one more important advantage - oscillations will penetrate into a material and create in it zones with quickly changing each other increased and decreased pressure that intensifies transport processes of moisture from deep stratums to a surface in the second phase of drying.

Other working factors of acoustic influence are:
- Reduction of liquid viscosity under influence of acoustic oscillations, it promotes an rapid carry of a moisture from deep stratums to a surface: extrusion of a moisture from a material the cavitation bubbles emergent in a liquid under influence of high intensity acoustic oscillations (the effect is observed only at a high humidity - 80 % and is higher), - the radiation pressure extruding a liquid from a material.

The liquid from a surface is deleted not only at the expense of evaporation (that requires the considerable power expenditures on realization of phase transfer), but also as an aerosol (without phase change) - which emergent at the expense of
influence of quickly changing pressure drops and cavitational processes. It reduces power expenditures of acoustic drying, in comparison from convective.

Acoustic processes and devices lab of Biysk technological institute together with LG Electronics corporation had been lead researches of possibilities of drying combined mode in a model at simultaneous thermal and acoustic influence.

II. THE CHOICE OF THE ACOUSTIC IRRADIATOR

During research in the capacity of high intensity acoustic oscillations source it was applied three different type of irradiators - two types rod-shaped gas-jet irradiators (a variety of Hartmann generators) and one type of piezoelectric irradiators.

Rod-shaped gas-jet irradiators have, among other aerodynamic irradiators, the most efficiency (up to 25%-30%) and ensure stable conditions of generation, do not require high pressures of a heavy air [5].

For practical researchs two variants of rod-shaped irradiators was designed and manufactured: a irradiator of the axial reflex scheme (figure 1) and a irradiator of the radial-funnel-shaped scheme (figure 2).

Comparative tests have shown that more effective is the reflex variant. It ensures a required sound pressure level at smaller compressed air consumption.

The sound pressure level, created by a irradiator for distance 0,3-0,4 m makes 135-140 decibel. Distance about 0,17-0,22 m there are local sections where the sound pressure level attains 145-150 decibel. Besides in separate zones the cavitation sputtering of water is observed, therefore, the sound pressure level in these zones attains 162 decibel. Working pressure of a compressed air for this irradiator has made 0,2 - 0,3 mega Pascal, at compressed air consumption about 0,19 m3/minutes.

Essential difference of acoustical resistances of metals and air do not allow creating with the help of solid-state irradiators (in an air medium) flat or spherical waves with a sound pressure level above 115-125 decibel. Therefore, at use of piezoelectric irradiators for making in an air medium of acoustic waves with a sound pressure level 130-140 decibel use a focusing (concentration) less intensive oscillations on the localized section. For a focusing of acoustic oscillations in an air medium the reflecting, lens or phased systems are used. Last represent the greatest interest as have the most prime design and small dimensions.

The piezoelectric irradiator [6] consists of irradiating disk (making a bending oscillation of the higher orders) and a piezoelectric ultrasonic oscillatory system of axial type

![Figure 1. Appearance gas-jet irradiator of the reflex scheme built in the frontal door of the washing machine](image1)

![Figure 2. Appearance gas-jet irradiator of the funnel-shaped scheme. (exciting oscillations of the disk) [7, 8]. A feed of the piezoelectric transducer by electrical oscillations ultrasonic frequencies is carried out from the specialized electronic generator.](image2)

In zone of a focal point the irradiator ensures intensity of ultrasonic influence 160 decibel - 170 decibel, near to zone of a focal point - 145 decibel - 160 decibel, in other points of an internal volume of washing machine drum - not less than 135 decibel.
III. MEASURING METHOD OF DRYING PROCESS PARAMETERS

Key parameter describing drying process is humidity of cloth which is defined as

\[ w = \frac{M - M_0}{M_0} \times 100\% \]

where \( M_0 \) - weight of dry cloth, \( M \) - weight of the wet cloth.

The absolute value of cloth drying speed is defined as \( v = \frac{(M_1 - M_2)}{t} \), where \( M_1 \) - initial weight of cloth, \( M_2 \) - a final weight of cloth (after drying), \( t \) - time of drying.

IV. MAKING MODEL

For practical research of drying process it has been created two models. First model intended for a choice of organization principle of drying process, such as a used irradiator, test of soundproofing system, measuring of acoustic field parameters. Physically, the first model manufactured on the basis of the washing machine «Vyatka Avtomat 16» which is a typical representative of drum-type washing machine (without the drying apparatus). In a design of a model the drum-type unit, framework and the frontal door are saved only; all other units have been deleted. During experiments with the first model, the possibility of increase of a speed drying process under influence of high intensity acoustic oscillations is shown. So, under equal requirements of air circulation in volume of a drum the speed of drying under influence of ultrasonic oscillations will increase by 43 % at drying a thin cloth. At drying a towel the speed last has increased under influence of ultrasonic oscillations created gas-jet irradiator on the average by 33 % and under influence of the ultrasonic oscillations created by a piezoelectric irradiator - on the average on 43 % (that on 15 % more than for gas-jet a irradiator).

Also the following is established:

1. The system effectiveness “the electronic generator - a piezoelectric irradiator” approximately in 10 times is higher than efficiency of systems “the compressor – gas-jet irradiator”. Besides at operation gas-jet a irradiator outside of washing machine mainframe there is the low-frequency acoustic noise created by a jet of a compressed air. The compressor used for a feed of gas-jet irradiator also is a noise source. Therefore for the further researches the piezoelectric irradiator has been used only.

2. Reduction of acoustic radiation level outside of washing machine mainframe up to a safe level (70 decibel) needs application of soundproofing. As have shown researches - enough one stratum self-adhesive cellular soundproofing material width of 8 mm, pasting on internal surface of mainframe and an external surface of an external drum.

The second model for research of drying process is created on the basis of washing machine (with built-in drying) LG WD14124RD, in view of the results obtained during researches on the first model.

At making a model it was required to satisfy a requirement of the complete saving of existing functionality of the base washing machine. It has defined the unique place accommodation of a piezoelectric irradiator - in the frontal door.

The glass hatch of the frontal door has been exchanged with the detail which has been carried out from high-strength heat-resistant plastic. The external surface of a plastic detail whenever possible completely copies the form of a glass, the form of an internal surface is carried out in view of a possibility of accommodation there a piezoelectric irradiator. The plastic detail of a hatch is fixed in regular door border of the washing machine. Appearance of the second model represented in figure 4.

Necessary suppression of a sound can be provided with drawing of one soundproofing layer on external surface of an external drum and an interior surface of mainframe.

Preparation, heating and air circulation during cloth drying is ensured with a convective drying system existing in the washing machine.

V. DESCRIPTION OF THE EXPERIMENTS AND EXPERIMENTAL RESULTS

For definition of influence efficiency of acoustic
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oscillations on drying process a series of experiments has been carried out. During these experiments cloth drying, as soon as for the score convective-thermal influence, and with application of acoustic oscillations was carried out.

For elimination of material type effect, possible losses at washing samples of one type cloth (cotton) have been used. It has allowed eliminating reallocation of moisture between samples from different materials.

Before the beginning of experiment rinse and expression of seven cloth samples in the washing machine was carried out. After expression weighing samples and their fillings on drying was carried out. Experiment was carried out in some stages duration for 5 minutes. After each stage samples were extracted from washing machine drum and weighed, then again were included in a drum. The first stage started on the “cold” washing machine, the temperature inside which did not exceed an environment temperature more than on 3 degrees.

For securing of results comparability of different experiments, all graphs have been normalize to equal starting conditions of cloth humidity after expression, equal 40%.

In figures 5-7 represented the graphical dependences obtained as a result of experiments results processing, where the washing machine air heater works at full power (2000 Ws) at realization of different variants of additional ultrasonic influence. On graphs the following labels are accepted: «w/o AI» - ultrasonic influence misses. «AI-A» - ultrasonic influence by an irradiator ¹ 1 (the steel concentrator) at an output power of the generator 310Br. «AI-B» - ultrasonic influence by an irradiator ¹ 1 (the steel concentrator) at an output power of the generator 500Br. «AI-C» ultrasonic influence by a irradiator with the titanic concentrator at an output power of the generator 250-280Br.

In figure 5 represented dependences of drying speed at different variants of power influence from time. On the graph 6 represented dependence of humidity time history on drying time first 15 minutes. In figure 7 represented graphs of humidity time history at the long-lived drying (25 minutes).

In connection with that the first stage of the indicated experiments last 15 minutes, the intermediate meanings of a humidity (5 and 10 minutes) rated (on the graph - will incorporate a hatch).

VI. THE ANALYSIS OF THE OBTAINED RESULTS

On the basis of obtained experimental data graphical dependences of drying speed time history and humidity time history was plotted, under different requirements of power influence.

Experiments on drying were carried out as in a base operation mode of air heater (2 kW, temperature of drying air up to 120 degrees), and at the reduced capacity (no more than 1 kW and temperature of air 62-65 degrees). Besides different piezoelectric irradiators were applied.

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In figures 5-7 represented the graphical dependences obtained as a result of experiments results processing, where the washing machine air heater works at full power (2000 Ws) at realization of different variants of additional ultrasonic influence. On graphs the following labels are accepted: «w/o AI» - ultrasonic influence misses. «AI-A» - ultrasonic influence by an irradiator ¹ 1 (the steel concentrator) at an output power of the generator 310Br. «AI-B» - ultrasonic influence by an irradiator ¹ 1 (the steel concentrator) at an output power of the generator 500Br. «AI-C» ultrasonic influence by a irradiator with the titanic concentrator at an output power of the generator 250-280Br.

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In figure 8 represented time history of drying speed, observed in experiments where capacity of a thermal influence was gradually reduced, and the temperature of drying air was supported in limits of

![Figure 4. Appearance of the second model](image)

![Figure 5. Time history of drying speed](image)
63-65 degrees.

Figure 6. Time history of humidity

In figure 9 represented time history of humidity. In figure 10 represented matching averaged data on drying speed at different variants of power influence.

Taking into consideration, that the power consumed by washing machine (LG WD14124RD) air heater in a normal mode makes 2 kW, power consumed by a piezoelectric irradiator in a normal mode makes 260 kW, and in a condition of heightened power of 500 Ws, has been calculated power consumption of drying at different power influences.

Results represented in table 1. In figure 11 represented graphs time history of cloth humidity, measured according to procedure ANSY/AHAM HLD-1-1992 [9].

Figure 7. Time history of drying at a long influence (25 minutes)

Figure 8. Time history of drying speed at decrease of thermal influence power with the purpose of maintaining temperature of drying air in limits of 63-65 degrees

Figure 9. Time history of drying speed at decrease of thermal influence power with the purpose of maintaining temperature of drying air in limits of 63-65 degrees

Graphs from left to right:
without ultrasonic influences and heating of air
with ultrasonic influence without heating air
without ultrasonic influences in a heating-up period of the washing machine
with ultrasonic influence in a heating-up period of the washing
machine
without ultrasonic influences on the washing machine after warming-up
with ultrasonic influence on the washing machine after warming-up
at heightened power
ultrasonic influences on the washing machine after warming-up
without ultrasonic influences at temperature of air about 60 degrees
with ultrasonic influence at temperature of air of 60 degrees.
Figure 10. Matching of the averaged drying speed at different
variants of power influence

| TABLE 1 MATCHING OF POWER CONSUMPTION OF DRYING AT DIFFERENT POWER INFLUENCES |
|-------------------------------------------------|-----|---------|
| The condition of influence                      | The total power, kW | Drying speed, gpm | Power consumption of drying for 1 gram water removal, Joules |
| Convective - thermal                            | 2   | 9.5     | 12.6               |
| Convective-thermal + ultrasonic a nominal power  | 2 + 0.21 | 12  | 11                |
| Convective - thermal + ultrasonic heightened power | 2 + 0.5 | 14  | 10.6              |
| Convective - thermal on the under capacity + ultrasonic a nominal power | 1 + 0.21 | 9  | 8                 |
| Convective - thermal on the under capacity without ultrasonic | 1 | 6  | 10                |
| Circulation of cold air + ultrasonic            | 0.33 | 4.4    | 4.5               |

Figure 11. A time history of cloth humidity, measured according to procedure ANSY/AHAM HLD-1-1992 at different aspects of power influence.

VII. RESULTS OF THE ANALYSIS

Results of the analysis obtained experimental data consist in the following:
1. Drying speed with application of ultrasonic oscillations is always higher than drying speed without ultrasonic influence;
2. Efficiency of drying will increase non-linearly with increase of ultrasonic radiation power;
3. The maximum of ultrasonic drying speed is ensured in an initial stage of cloth drying having maximum humidity;
4. The maximum speed of drying has made 14 gpm at maximum implemented emissive power (about 500 Ws of a consumed electrical power with a steel irradiator);
5. The optimum speed of drying makes 12 gpm (about 350 Ws of a consumed electrical power with a steel irradiator or about 200 Ws of a consumed electrical power with a titanic irradiator);
6. Faster increase of a speed in initial stage of drying at ultrasonic influence explains by lack of inertia of ultrasonic influence, as contrasted to thermal;
7. The faster collapse of drying speed at ultrasonic influence explains faster decrease of a humidity.

CONCLUSION

On the basis of the obtained results, it is possible to formulate the following conclusions on work:
1. The integration of acoustic drying system into washing drying machine provides increasing the drying features by increasing the drying and decreasing energy consumption;
2. The energy consumption of drying process decreases with increasing the acoustic radiation power;
3. Maximal growth of drying speed by acoustic influence provides on initial drying period when the cloth and air into drum are cold and cloth humidity is high;
4. the most advantages of drying process with acoustic influence in comparison with drying without acoustic influence obtains when air temperature in drum is low.

Together that, the constructive scheme with an arrangement of one irradiator in the frontal door brings in a line of limitations and does not allow to implement a potential of ultrasonic drying to the full. Therefore, on the basis of the obtained experimental data, the lead analysis and the made outputs authors consider, that the further increase of drying efficiency at integration of cloth ultrasonic drying system in the washing machine can be reached at realization of researches in the following directions:
1. Increase of efficiency of radiation and decrease of piezoelectric irradiators power consumption, at the expense of use of high-strength materials (titanic and aluminum alloys for realization of concentrators and the plates making a bending
oscillation and concentrating radiation), increase and a deformation of a irradiating surface of plates making a bending oscillation. Thus, at realization of the indicated provisions at increase of a consumed electrical power of a reactor in 2 times (up to 400 Ws) efficiency of moisture removal will be enlarged not less than in 2 times.

2. Perfecting existing, and making of new constructive schemes of irradiators accommodation.

3. Change of the constructive form of the washing machine in view of singularities of formation and interaction ultrasonic oscillations with cloth.

4. Optimization of drying process with use high intensity ultrasonic oscillations.

Thus, additional researches and deriving of new knowledge can advance a solution of problems of ultrasonic drying essentially.

REFERENCES

[1] The Russian Federation patent №2221094


Denis S. Abramenko – was born in Biysk, Russia, 1982. He received degree on information measuring engineering and technologies from Altay State Technical Institute. He is post-graduate student of Biysk Technological Institute. IEEE Student Member.

Sergey N Tsyganok was born in Biysk, Russia, 1975. Now he is Ph.D (Machinery), he received degree on information measuring engineering and technologies from Altay State Technical University, key specialist of electronics. Laureate of Russian Government premium for achievements in science and engineering. His main research interest are development of high -effective multifunctional oscillators for ultrasonic technological devices.

Roman V. Barsukov was born in Biysk, Russia, 1975. He received degree on information measuring engineering and technologies from Altay State Technical University, key specialist of electronics. Laureate of Russian Government premium for achievements in science and engineering. His main research interest are development of high –power electronic generators for ultrasonic technological devices.

Andrey N. Lebedev (S’03) was born in Kiselevsk, Russia in 1983. He received degree on information measuring engineering and technologies from Biysk Technological Institute of AltSTU. He is post-graduate student of Biysk Technological Institute. His research interests is finite-element modeling.