DASFOS Czr, s.r.o. Technology-innovation center
Bozkova 45 14, 702 00, Ostrava 2-Privoz, Czech Republic
Phone: + 420 59 6612092 Fax: + 420 59 6612094
E-mail: dasfos@dasfos.com Web: http://www.dasfos.com

Technical Information

to the

RF-33/TV/RDI

system for testing high-temperature physicochemical properties
of metallurgical materials in the environment of technological gases

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General

The RF-33/TV/RDI system consists of several separate parts which can be assembled in various modifications according to the intended use. Its advantage is that it can be extended or changed whenever needed to perform a non-original test task. The system is primarily designed for testing of iron ores, agglomerates and pellets (according to the Standards ISO 4695, ISO 7215, ISO 4696-1 and ISO 4696-2), when designated as the RF-33/TV/RDI. After addition of the relevant software and retort, it can also be used for coke quality testing (according to ISO 18894 or ASTM D 5341 Standards). Such modification is then referred to as RF-33/TV/CRI/RDI. The versatility of the RF-33/TV/RDI system also allows, after addition of relevant software and a coking retort, production of about 10 kg of coke under laboratory conditions. This modification is referred to as the RF-33/KK/TV/RDI type. The functions of each system variant are described in more detail in the relevant technical materials.

The RF-33/TV/RDI equipment is designed for the research of high-temperature physicochemical properties of metallurgical materials in the process gas environment. This means high-temperature testing of metallurgical materials (raw materials), especially iron ores, sinter and pellets, as well as solid fuels, especially coal and coke. This extended modification of the original RF-33/TV system completely meets the requirements and requirements of the International Standards SO 4695, ISO 7215, ISO 4696-1 and ISO 4696-2 for the testing of iron ores, sinter and pellets. There is software that allows you to set up your own test schedule, including the timing of up to four test gases flows. Thus, for example, a complete CRI test for coke according to ISO 18894 or ASTM D 5341 Standards can be arranged. In addition, the software also allows for doing scientific experiments (non-standardized tests).

The RF-33/TV/RDI device consists of a special vertical resistively heated furnace for heating a retort with the test sample, a thermo-scales system, a retort cooling device, a device for automatic insertion and taking-out the retort in the system "furnace – cooling box", a test drum according to the ISO 4696 -1 and 2 Standards. It also includes a process gases distribution system and exhaust gas discharge system. Controlling the course of the computer test ensures the automated control of the entire device, including registration of the test process results. Controlling the test course by a computer ensures the automated control of the entire device, including registration of the test process results.

1. Essential parts of the RF-33/TV/RDI system

are as follows:

- WA 1100 vertically openable test furnace
- Gas management system for CO2, N2, CO, and H2 gases
- Process control system with SPW-2 type control computer
- Sample weighing system during test (thermo-scales)
- Test retort according to ISO 4696-1 and ISO 4696-2 Standards
- Rotary testing drum according to ISO 4696-1 and ISO 4696-2 Standards
- Movable cooling box
- Handling trolley with retort holder
- Electronic scales for weighing samples and sample residues after the reaction
- CO leakage and off-gases combustion control system
- Accessories for sample preparation and evaluation.

1.1 Vertically openable test furnace WA 1100

The WA 1100 test furnace allows two types of working modes:

a) Test mode of heating of the test retort according to fixed ISO parameters
b) Mode of heating and gas flow in the retort according to the pre-assembled plan (the so-called "TEST PLAN").

Technical parameters of WA 1100 vertically openable test furnace meet (among others) all the requirements of ISO 4695, ISO 7215, ISO 4696-1 and ISO 4696-2.

The WA 1100 is a two-zone, vertically split furnace. This design allows the operator to easily and safely handle the test retort. Each of the heating zones, i.e. upper and lower, has a separately measured and controlled temperature using a special control algorithm. The aim is to create a stable temperature zone in the test sample area throughout testing. At the position of test sample a very stable temperature is thus achieved. The temperature stability during the tests can be verified by an independent measuring method. Location of the measuring thermocouple directly in the space between heating spirals and the test retort allows the controller to respond quickly to changed external conditions such as a drop in the supply voltage (up to + 10 / - 20 % in the grid), changes of the ambient temperature, air flow, etc. A great advantage of the used heating modules is their low thermal inertia. The CANTHAL heating spirals do not heat up the work space through other elements, such as ceramic pipes, but act directly into the workspace.

Temperature regulators are components of the computer control system, and control is implemented using sophisticated algorithms. The actuators for each heating section are thyristor units specially designed for this purpose. The maximum allowed temperature in the furnace is 1150 °C; short-term maximum is 1200 °C. The temperature of individual heating sections is regulated according to the desired parameters with accuracy better than ± 1 °C.

This test furnace does not require any additional transformer, stabilizer or suppression choke, it is powered directly from the public network 3 x 400/240 V. The furnace design allows, by simple replacement of the upper and lower part of thermal insulation, use of test retort of different diameters, from 60 to 130 mm.

1.2 Gas management system for CO_2, N_2, CO, and H_2 gases

Gas management means the distribution of process gases (CO_2, N_2, CO, H_2) to the test furnace and the relevant back, control and shut-off valves. Measurement of instantaneous flow of individual gases is carried out by means of OMEGA type FMA-A2409-SS flowmeters/controllers. The individual gas flows are controlled with accuracy better than 1% in quantity and time sequence according to prescriptions of the relevant Standard. To control the test run and to check for any return pressure at the outlet, differential pressure is measured between the inlet gas pressure to the retort and the outlet pressure from the retort. After placing the retort into the furnace, its gas tightness is checked by inert gas pressurization when the outlet valve is closed. This is a very important precaution - if there is a gas leakage, the test cannot be started. Similarly, it is possible to test the gas tightness of the gas supply pipes from the reduction stations. During the test, the inlet and outlet pressures of the gases from the retort are measured, and the correct flow of the exhaust gases is monitored by use of software evaluation.

It is assumed that the technical gases used have the required laboratory purity and also the other physical parameters as prescribed by the Standard.

A special safety sensor for controlling the leakage of CO and H_2 gases is installed and the control system continuously monitors the laboratory environment. If a hazardous situation occurs during the test, the control system shall, in addition to signaling the dangerous leakage of gas, terminates the test automatically.

1.3 Process control system with SPW-2 type control computer

Control of the entire system is provided by the control computer. A standard PC system with interface cards is used. Since the latest motherboard is always used, we do not type it here. The computer is part of the RF-33/TV/RDI system. Its HDD is divided into three partitions:

- Operating system and drivers
- Control and test programs, archive of tests performed by the RF-33/TV/RDI system
- User programs (Word, Excel, etc.)

All measurements are processed by the computer via interfacing measurement cards. Computer system controls the temperature course and its stability in individual sections of the test furnace. By measuring the actual temperature in the test retort, individual heating sections are controlled so that the temperature of the test sample in the retort is stable and at the value prescribed by the relevant Standard. The control system allows monitoring of the temperature field distribution in the retort i.e. practically directly in the test sample. Temperature regulation is solved complexly by means of digital control algorithms; it is multi-parametric with established auxiliary quantities such as supply voltage, ambient temperature, actual gas flow, and temperatures from temperature field measurement. The algorithms used are adaptable using the recorded history of parameters and responses in the previous tests.

The control program includes measurement procedures and control of digital controllers for individual technological gases. This makes it possible to regulate and control the flows of individual technological gases with high resultant precision. The control computer also directly controls the functioning of the test drum in tests according to ISO 4696-1 and ISO 4696-2 Standards i.e. the actual rotational speed with measuring time and total number of drum revolutions.

The system is equipped with electronic weighing scales for weighing the test samples before and after tests, being connected to the control computer which records individual weights and automatically evaluates the test results. This allows efficient and detailed processing of all measured values, as well as long-term data archiving and processing of final test reports, and, if necessary, the use of digital photo documentation.

The control of the entire test according to ISO 4695, ISO 7215, ISO 4696-1 and ISO 4696-2 Standards is fully automated by means of a control computer. The operator selects the Standard according to which he intends to perform the test, and then proceeds in accordance with the relevant manual. Individual steps and procedures of the tests are also automatically checked, both continuously throughout the test and also after the test.

At the beginning of the test, the operator places a prepared retort with the test sample on the hanger on one side of the test furnace and connects the necessary connectors (measuring cable, gas inlets and outlets). Once the process is started by the operator, and after the furnace temperature has reached the desired value, the retort automatically (using rail on which it is hung) enters the test furnace that has been opened in the meantime. The

heating-up of the furnace is very fast due to the high-quality heat-insulating materials of the heating modules.

In order to obtain a time record of the sample weight loss during the test, the initial weight of the retort with the sample is balanced out to zero value by the weighing device, so that only the weight changes of the sample are then determined by continuous weighing. For tests that do not require the use of that feature, retort is suspended on the boom throughout the test.

Upon completion of the test, in time compliance with rules of the relevant Standard, the retort will automatically exit the test furnace and remain suspended on the boom until it is cooled to requested low temperature. Cooling the retort is done in a mobile cooling box by use of a fan. Inside the box, temperature is measured nearby the chilled retort. Full cooling down of the test retort to the desired temperature is signaled to the operator, which can then safely manipulate the retort. In this way, since the furnace does not need to have a furnace cooling cycle before the next test, it is ready for a new test almost immediately. If a high testing cadence is required, then at the time of the test, a second test sample retort is already prepared and placed on the hinge of the boom which is at the time outside the test furnace. At the end of the test, the boom moves to the other side, so that when one retort goes out of the furnace, the other can go in and the next test can begin. To the retort, which has been removed from the furnace, a transport trolley with a cooling box is moved in which the retort is closed until fully cooled down. After that, the retort is moved to the side by means of the trolley and the retort top cover is opened by means of a key. The remainder of the sample after the test is dumped into a prepared vessel and weighed on electronic scales.

The system allows testing to be monitored and controlled from a remote PC computer via ETHERNET network connection. In this case, the immediate presence of the operator is not required in the laboratory. Moreover, if the system can be connected to the Internet network, then such remote control method is also possible. In this way, DASFOS regularly checks its installed equipment, especially when situated abroad.

1.4 System for sample weighing during test (thermo-scales)

The thermo-scales weighing system of this design, if correctly adjusted, has a verifiable determining accuracy of 0.5 g, as determining the change in weight of the test sample is concerned. The verification of weighing sensitivity and accuracy is done by a weight placed on the top cover of the retort. Weighing accuracy can be checked at any time during the test. It is advisable to use a calibrated weight (0.5 g or 1 g) for the checking.

By a special program included in the delivery, it is also possible to determine and quantify the influence of the outside thermal flows on the thermos-scales functioning, and to compensate it. It is also possible to determine and compensate for the effect of gas flow in the retort. Thus, it is possible to carry out experiments investigating the effect of the gas pressure changes in the retort on the time course of sample weight loss during the test.

1.5 The test retort according to ISO 4696-1 and ISO 4696-2 Standards

The 900 mm long retort is made of a thick-wall steel tube (stainless heat-resistant steel) with a diameter of 75 mm and thickness of 5.5 mm. The retort is provided with top and bottom lids. The grid for placing the measured samples is made of 5 mm thick heat-resistant steel sheet. Preheating of process gases is accomplished by passing through a layer of ceramic balls (of 12 mm diameter) that are situated in the retort between two grids.

Retort is equipped with one or five thermocouples. For common tests according to the Standards, one central thermocouple is sufficient. When measuring and monitoring the temperature profile in the retort is required, the retort is ready for further 4 thermocouples to be added.

The retort is composed of several parts that are independently replaceable in the case of wear:

- The body of the retort. A tube made from heat resistant steel and provided with threads at its ends for connecting of closing lids. Such pipes are commonly manufactured by all major steel tube manufacturers. The material we use is the SEV 470 1.4841-C2-S from DMV STAINLESS France. The lifetime until tube replacement, at temperatures of 1100 °C in a carburizing atmosphere ranges from 200 to 250 tests performed. For tests performed at lower temperatures (below 1000 ° C), the lifetime of the retort body increases dramatically.

- Top lid with hanger, gas outlet, and input hole for temperature checking

- Bottom lid with gas inlet, gas-tight inlet for one or five thermocouples, grate for gas preheating balls, and spacer

- Sheathed thermocouples, type K

- Collar to limit the influence of circumjacent thermal flow. The retort is equipped with a special collar that seals the gap in the thermal insulation of the test furnace. This radically restricts the hot air flow around the retort in the furnace during the test.

The upper lid is provided with a filling opening, which is closed gas tightly after the test sample is put into the retort. Its diameter is such that it is not possible to use sample material of larger pieces than the Standard prescribes. In the upper lid there is also a gas outlet. For independent checking of accuracy of the common temperature measurement by an independent method, there is a special opening in the lid for the inserting of a calibrated thermocouple with higher accuracy (class 1). This thermocouple is a sheathed Pt-PtRh 10 type. Comparison of the both measured temperatures is carried out in a special, for this purpose determined mode. The result is automatically evaluated by the software.

The lower lid is equipped with a special outlet which serves to adjust and hold the grates at the prescribed distance in the retort, both for the supply of process gases and for the outlet of the individual measuring thermocouples. This solution is original and has many advantages. In particular, the material of the retort is not damaged at the position of grate, on which the sample lies during the test. Another advantage is a reliable thermocouple outlet that is not affected by hot off gases, thus allowing for a more stable temperature measurement of the test sample. There are also outlets prepared for four additional thermocouples if the need arises to study the temperature field in the test specimen at different height levels. Temperature monitoring is important for controlling and stabilizing the temperature conditions for individual test samples.

1.6 Rotary testing drum according to ISO 4696-1 and ISO 4696-2 Standards

- internal length	200 ± 1 mm
- internal diameter	130 ± 1 mm
- wall thickness	5 mm
- bottom thickness	10 mm
- ribs	height 20 mm, thickness 2 mm
- drum drive	regulated electric motor

- rotational speed	30 ± 0,1 rpm
- revolution counter	contactless
- speed control	control system, timer

The rotary drum is equipped with a safety cover and a safety switch. If the cover opens, the drum drive will shut off automatically.

1.7 Movable cooling box

The cooling box is mounted on one side of the handling trolley. It is made of stainless steel and is vertically openable. Rapid cooling down of the retort is ensured by a radial fan. Since the box is mobile, it is very easy to place the retort after the box is opened. The retort, which on the rail automatically goes out of the opened furnace, is thus simply enclosed in the cooling box. The hot air from the cooling box can be taken out to the central exhaust of the laboratory. Handling the retort during cooling down is completely safe and comfortable for the operator. For some tests (depending on the Standard used), the retort remains connected to N_2 supply in order to block further course of chemical reactions during the retort cooling.

During the cooling by a fan, temperature is measured in the box space nearby the retort. Once the requested temperature has been reached, an audio and visual signal for the operator is initialized meaning it can be further manipulated with the retort. After cooling down, the retort is ready for performing a new test or is hung in the retort holder at a convenient location in the lab.

1.8 The handling trolley with retort holder

Stored retorts are standardly located in a retort holder, which is installed on the laboratory wall or at the site reserved for storing retorts. All the retort handling during tests (placing the retort into the retort holder, opening and closing the retort, inserting the test sample, hanging the retort onto the furnace boom, etc.) is done by use of the handling trolley. Therefore, the retort handling is simple and safe, so there is no collision or injury risk when respecting rules given by the Instruction Manual. The operator never has to move the retort manually. Non-negligible may also be, in some cases, the low required building height in the laboratory, as there is no need for a crane cat for moving the hot retort after the test is completed.

The handling trolley has, on one side, the cooling box and, on the other side, an openable retort holder. The retort is fixed in the holder by use of a robust, flexible buckle. The holder is vertically slidable with a trapezoidal screw with a nut.

1.9 Electronic scales for weighing samples and sample residues

For weighing test samples and weighing individual fractions of sample residues after the reaction, a precise electronic weight scales with a capacity of 600 g and a resolution of 0.01 g is used. The apparatus is equipped with automatic tare and electrical connection for data transfer and weighing control.

1.10 CO leakage and off-gases combustion control system

The sensor for hazardous gases concentration is located at the prescribed height above the test furnace. It can either work independently with audio and visual signaling, or it is connected to the computer system which, in the event of a dangerous gas leak, performs

adequate intervention and terminates the current test. The sensor can also be connected to the laboratory's security network.

For combustion of waste gases from the retort, the device is equipped with a safety burner. The burner functionality is controlled by monitoring the flame temperature by a built-in thermocouple. The flue gas outlet may be into the open air or into the extractor hood.

1.11 Accessories for sample preparation and evaluation

Sorting stainless steel screens according to the requirements of ISO 4695, ISO 7215, ISO 4696-1 and ISO 4696-2 Standards.

2. Input data for the test and provided test results

2.1 Entering the input parameters

In addition to the mandatory data, i.e. the:

- certificate number
- name of the Standard under which the test will be carried out
- mesh size used to prepare and evaluate the sample
- weight of the laboratory sample taken (if less than 50 kg)
- operations carried out, if they are listed as non-binding in the relevant ISO Standard
- date of preparation of the sample for the test
- name of the operator doing the test,

these may be supplemented by entering other appropriate data as required by the user.

2.2 Results - protocol

The test report includes the above mentioned input parameters for the given test, the date of the test, and the automatically processed results of the test carried out:

- weight of the individual fractions of the sample residues
- total reaction time
- total volumes of CO_2, N_2, H_2, and CO gases used for the test
- max. temperature deviation during the reaction
- max. deviation from specified drum rotational speed
- calculated indices and their comparison with mandatory standard criteria.

Additional test parameters and notes to the test may be added to the report as required by the user. The printed report may include the following optional graphics, i.e. the:

- time course of loss of sample weight during the reaction
- temperature of the medium thermocouple during the test
- temperature profile of the temperature profile (if the appropriate thermocouples have been installed)
- time course of actual gas flows during the test
- temperature of the furnace sections during the test
- actual speed of the test drum during tests according to ISO 4696-1 and ISO 4696-2
- time record from the CO analyzer in the exhaust gases (if installed).

2.3 Archived data

All measured and regulated parameters of all tests are archived. Subsequently, these can be presented on the screen or printed, either ordered by the date of testing, or by the number of the "atest" (test protocol) that is automatically generated.

The test results are also archived in form of *.csv files, designated to be processed by a spreadsheet processor.

In special files, a time archive of all system manipulations is stored, including records of failures detected during automatic checks.

Before and after the individual tests, photographic documentation of test specimens by a digital camera may be carried out. Copied digital photos can also be archived and printed in the final test report. The computer must be equipped with an appropriate program.

3. Technical parameters of the RF-33/TV/RDI system

3.1 Vertically openable electric furnace WA 1100

- maximum furnace temperature	1 200 °C
- kiln operating temperature	1 000 °C
- length of stabilized temperature area	> 400 mm
- furnace design	replaceable heating blocks (from serial production)
- heating power	9 kVA
- current and voltage measurement	each heating block separately
- temperature control	digital, by thyristors actuators
- retort position in the furnace	vertical
- opening the furnace	automated
- inserting retort into furnace	automated – by electric drive
- temperature alarm	automatically

3.2 Continuous weighing of the test sample in the oven during the test

- weighing method	compensatory
- way of starting weight balancing	lever methode
- compensatory weighing	by accurate electronic scales
- weighing accuracy	0.02 g
- weighing range (max.)	6100 g
- tare range (subtractive)	6100 g
- reproducibility	0.04 g
- linearity	± 0,1 g
- calibration points	2/5/6 kg
- electrical output	RS 232
- verifiable weighing accuracy	0.5 g (for the whole system)

3.3 Process control system – SPW-2 type

3.3.1 Control unit

- CPU	3.0 GHz CPU, 2 GB DDR2 667 MHz RAM
- monitor	19 "TFT LCD
- HDD	160 GB
- FDD	3.5 ''

- keypad	wireless
- mouse	wireless
- color printer	HP
- remote access (Internet)	TeamViewer 7
- computer connection	Ethernet 10/100 / 1G
- measurement interface units	IDAM, TEDIA

3.3.2 Temperature control in furnace and retort

- way of controlling	by software
- control accuracy	better than ± 1 ° C
- max. temperature deviation in the retort during the test	± 1 ° C
- zone of stable temperature	> 400 mm

3.3.3 Control of the drum rotational speed

- way of controlling	by software
- control accuracy	better than ± 0.1 rpm

3.3.4 Control of gas flows

- method of flow measurement	by mass flowmeters
- measuring range (max)	50 l/min for N_2, 5 l/min for CO and CO2, 1 l/min for H_2
- used regulators	manufactured by OMEGA (USA)
- resulting control accuracy	± 1%

3.4 The test retort

- made of	heat resistant stainless steel
- retort length	900 mm
- retort ending	flanged
- inside diameter	75 mm
- wall thickness	5 mm
- bottom thickness	10 mm
- preheating of gases	through a ceramic balls layer
- measurement of retort temperature	by sheathed thermocouple(s)
- grate for sample placement	heat resistant stainless steel
- checking the retort gas tightness	automatic
- checking the piping gas tightness	automatic

3.5 Cooling box

- design	mobile
- method of retort cooling	forced, by a radial fan
- temperature measurement	thermocouple type K (E)

3.6 CO detection system

- sensor	fixed, located above the furnace
- function of the system	alarm, automatic terminating of test

3.7 Precise electronic scales for sample preparation and post-test weighing

- weighing capacity	600 g
- resolution (1 d)	0.01 g
- accuracy verifying	by external calibration
- electric output	two-way RS 232
- tare function	yes
- protection rating	IP 54

3.8 Accessories for preparation and evaluation of samples

Sorting stainless steel screen according to the requirements of ISO 4695, ISO 7215, ISO 4696-1 and ISO 4696-2

4. Software of the RF-33/TV/RDI System

4.1 Base programs

- operational system	Windows 7
- visualization	"DELPHI" environment
- remote access	TeamViewer by Internet

4.2 Programs for doing the tests i.e. for:

- managing the test and entering data into the input protocol
- digital control of temperature
- archiving certificates *(attests)*, displaying and printing the resulting report
- automatic checking of measurement procedures compliance during testing
- creation of databases
- creating files for spreadsheet processing

4.3 Service programs

- KOMUNI	internal communication management
- PICTURE	visualization program
- ARCHIVE	archiving program
- KOMOF	external communications management

4.4 System testing programs

- KANALY	checking measuring chains,
- TST_A	testing special units,
- TST_O	testing galvanic separators,
- KERN	testing and calibration of the thermos-scales

4.5 System diagnostics

HISTORIE	a program for automatic diagnostics throughout the tests.