NEW GENERATION FRICTION WELDED DRILL PIPE

Drill pipes for directional drilling, that we shall call simply ddr (acronym of directional drilling rod) represent one of the most important components for drilling installations. Their importance comes from the fact that the overall performance of drilling installations in terms of minimum curve radius and maximum pull-back length depend essentially, on a par with the performance of the machine, on the *ddr* that is used. Rod lacking in certain mechanical characteristics does not allow a good enough performance even when the rest of the machinery used is optimal.

Apart from its mechanical performance, the *ddr* can also allow the reduction of operating costs through reduction of the internal hydraulic resistance that the fluids used come up against when flowing through the drill stem. With this aspect in mind, the Colli Drill Pipe DDR LIHR represents an innovation in the field of drill pipes for directional drilling.

CHARACTERISTICS

In directional drilling, the main characteristics needed for the *ddr* are a high elasticity and a high mechanical resistance. It is known that the drill stem is subject to a series of external forces and deformations that puts each individual section of rod under an extreme state of mechanical stress, during directional drilling.

The external forces are those transmitted to the drill stem from the rig and also when the situation arises, from the down the hole hammer. Each individual section of pipe is subject to stress from an intense series of different forces among which the following are nearly always present: tension or compression, flexure, torsion, impulse forces of combined tension-compression (due to the use of the down the hole hammer).

The flexional forces can arise from the fact that the pilot hole is nearly always curvilinear (particularly in the zone of the entry and exit of the hole). The rods are thus forced to rotate into a hole with curvilinear profile, that is, under the action of an external imposed deformation which is equivalent to an applied stress. The ideal type of steel for the manufacture of the *ddr* should therefore have a high elasticity in terms of yeld point $R_p0.2\%$, in such a way as to allow large deformations in use (without permanent deformation after use) under the action of extreme forces.

For example, for a drill stem made up of rods with 60.3 mm external diameter and 47.4 mm internal diameter, put under stress by a rig able to produce 5,000 Nm of torque and 130 kN of pullback, moving around a curve with a radius of 20.0 m, the section under highest stress is subject to a maximum tensile force of 535N/mm^2. This figure falls to 458N/mm^2 if the radius of the curve increases to 30 m. The maximum force greatly increases if the down the hole hammer is used.

This simple example above shows how for the manufacture of *ddr*, exceedingly high specification steels are required.

For the manufacture of the Colli Drill Pipe DDR LIHR a high resistance steel is used (42CrMo4) the minimum mechanical characteristics of which, prescribed in the European Norm EN 10083 part I, are Re=900 N/mm^2 (yeld point) and Rm=1,100 N/mm^2 (ultimate tensile strength). These are very high values even when taking into account the good resistance to shock loading that this steel has (KV=30J).

LIHR is a friction welded drill pipe. For the welding of such a particular type of steel, a friction welding process has been developed using a successive heat treatment process (with an induction unit) which guarantees the production of joins with a resistance and resilience equal to, if not better than, the base metal.

The main advantages offered by *ddr* made by assembling tube to pre-machined tool joints are the following:

First, the tool joints are entirely turned on numerically controlled lathes. In this way, as well as obtaining an high quality finish on the threads and on the external surfaces in general, it is possible to obtain rigorously controlled surfaces and roughness for converging, diverging and minimal internal ducts. This aspect is very important because it contributes to the reduction of the hydraulic resistance that is present on the inside of the rod bringing the benefit, as we shall see, of an appreciable reduction in drilling cost.

Second, the tool joints can undergo appropriate heat treatment (i.e. nitriding) that guarantee a high resistance to the threads, foreseeing the problem of them seizing, and facilitating the setting up and breaking-off operations of the drill stem.

This is not possible for example for one piece forged rods in that particularly for converging and diverging parts (that anyway are not differentiated) it is impossible to work the internal surfaces of the connections on a lathe, with the result that the finished article has parts of the internal ducts (converging and diverging) that can-

Figure 1.

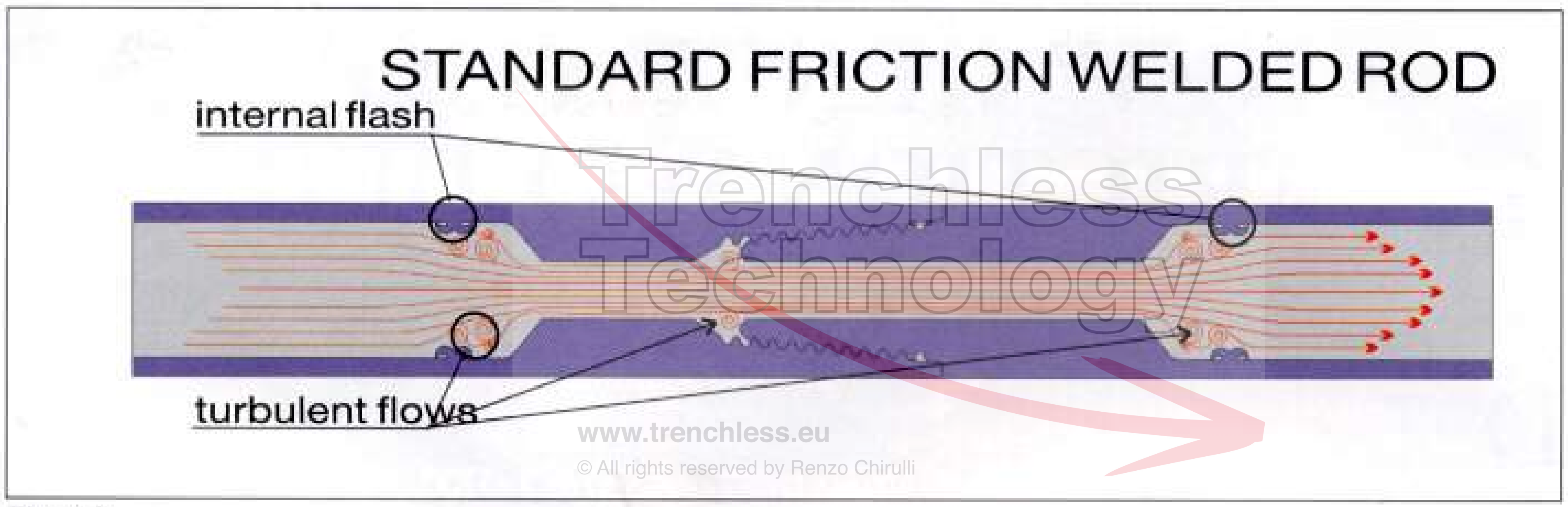

Figure 2.

not be made to conform to any satisfactory form or finish.

From a hydraulic point of view, a drill stem is basically a long tube in which a series of energy transformations take place with the motion of the fluid during use (air, water, mud). Not all the original fluid energy (kinetic and energy due to pressure) is in a useable form at the end of the drill stem. A part of the energy is transformed during the passage of the fluid into energy forms that cannot be used for the required application.

Generally, the energy which cannot be used is that found in the form of heat or kinetic energy arising from the turbulent motion of the fluid present in certain tracts of the tube. These energy transformations that represent for us losses are due to three main causes: The fluid is not an ideal fluid meaning that it has a certain internal friction or viscosity; the walls of the tube create a certain resistance to the movement of the fluid due to the friction between the fluid and the walls of the tube; and along the drill stem there are sharp changes in cross section (particularly at the connections between rods) where turbulence in the fluid occurs.

Concentrating our attention on the third of these above aspects, it is easy to see how in the connection between two full O.D. type rod (Fig. 1), there is a reduction of the cross section (converging) followed by a brief passage having a constant cross section (the minimum internal duct) which in turn is followed by an increase in cross section (diverging).

In the areas of connections between rods, there is highly turbulent flow, the intensity of which (with other variables remaining constant) varies as a function of the geometry of the various parts that make up the connection between rods.

As far as the minimum internal duct is concerned, two important aspects should be remembered: That the hydraulic resistance along the drill pipe will increase with a decrease in diameter; and the turbulence present in the converging and diverging sections will be more intense the smaller the ratio of the smallest internal cross section (the minimum internal duct) is to the cross section of the tube.

As has already been noted, the energy transformed into a non useable form represents for us lost energy. The greater this energy loss is, the less the flow and/or the pressure of the fluid at the drill stem exit will be. This can be seen as a lower productivity in the drilling (meters/day) and as a larger consumption of energy by the equipment used to pump the fluid (pump, compressor), and so in general as an increase in the overall unit cost of drilling.

There exists therefore, a component of the production cost that varies as a function of the hydraulic characteristics of the *ddr* used.

To reduce this component of the overall cost, one should look at the causes which give rise to the hydraulic resistance talked about above.

The friction between the tube walls and the moving fluid depends, among other things, on the roughness of the walls. A high quality finish of the walls can produce a noticeable reduction in the hydraulic resistance. Another parameter on which it is possible to act, again to reduce the hydraulic resistance, is the internal form of the internal ducts in the area of the rod connection.

If these connection parts of the rod (in particular the converging, diverging and minimum internal duct) are well designed then the areas where turbulence occurs can even be eliminated with a notable reduction in the energy loss.

LIHR

The *ddr* LIHR (low internal hydraulic resistance) has been designed with the objective of significantly reducing the energy losses related to the connection between rods.

If we look at a longitudinal section of the connection between normal sections of a drill pipe that have been friction welded (fig. 2), we immediately notice the internal flash that results from the welding operation. This flash gives rise to (in an area

Figure 3.

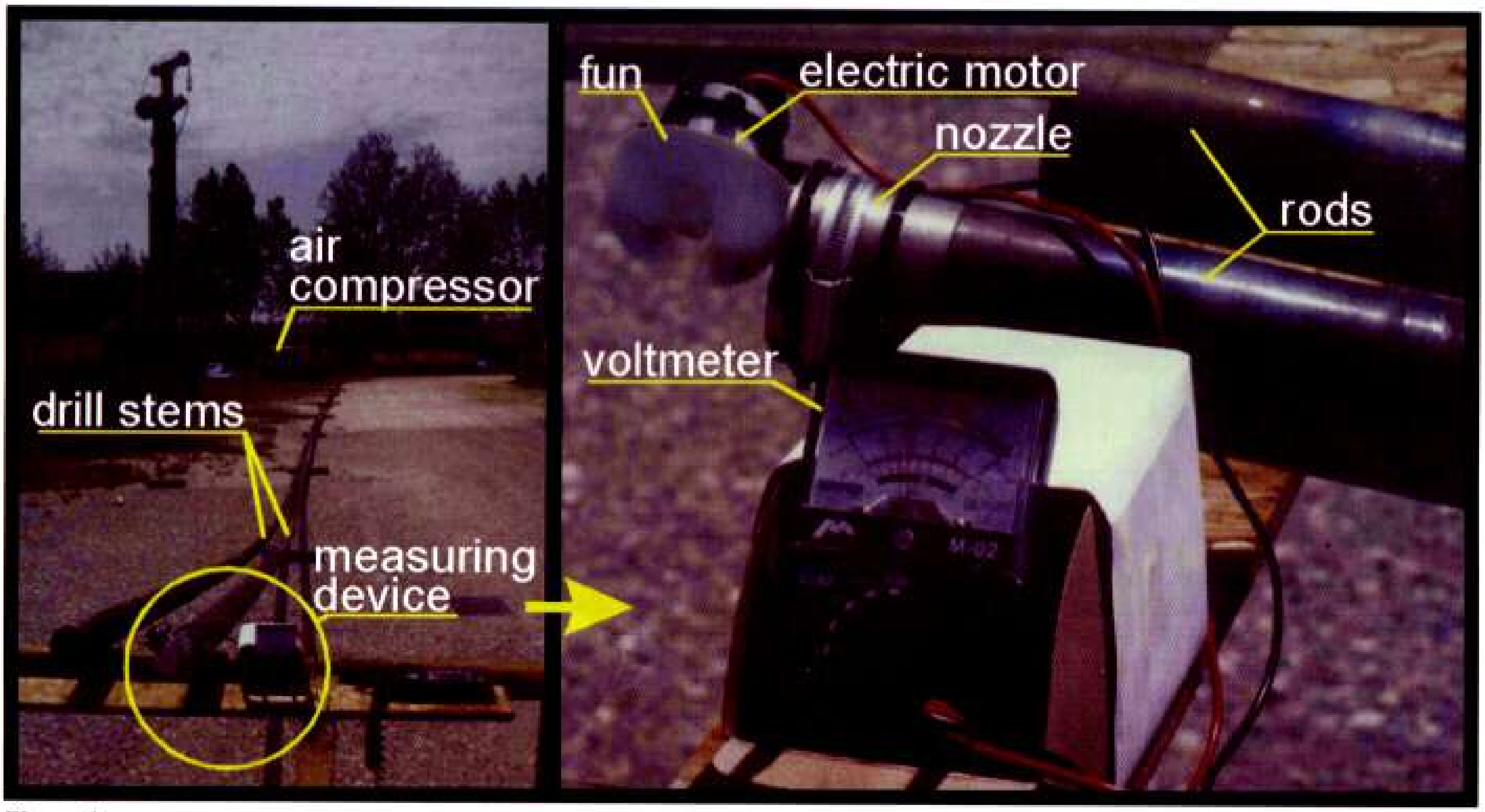

Figure 4.

which is already sensitive to the fluid flow) more hydraulic resistance which causes turbulence in the fluid and so a certain loss in useful energy.

In the design of the LIHR series, one of the first problems tackled was thus to produce a join (friction welded) that didn't have this typical internal flash.

This was possible thanks to the development of a particular friction welding technique (internationally patented by Colli Drill and FWA covering all PCT countries) used in the manufacturing stage of the *ddr* which encases the internal flash.

After much study and above all after much experimentation, excellent results have been produced. The internal flash is perfectly integrated in the body of the tool joint and the mechanical strength (breaking strain and resilience) is equal to that of the base material. Eliminating the internal flash, it has been possible to optimize the rod function from a hydraulic point of view.

To solve this second problem, hydraulic profiles were studied being different for converging and diverging tracts. This means that the LIHR rod can be used in just one direction.

The special form of the internal ducts in the converging and diverging parts guarantees a noticeable reduction of the turbulent zone (Fig. 3).

TESTS

To measure the effect of these design innovations, various simple experiments were undertaken which are very easy to reproduce. For these tests, normal friction welded *ddr* (X-series type) and LIHR type *ddr* were used (both produced by Colli Drill S.r.l.)

Both the rods used (full O.D. type) had the following characteristics: 3 m long, external diameter 60.3 mm, internal diameter 47.4 mm minimum passage internal diameter 20 mm. Each drill stem was made up of 20 sections giving a total length of 60 m.

The two drill stems (which were perfectly aligned alongside each other in such a way as to have identical paths (fig. 4)) were first supplied with air as the fluid and then with water.

The velocity of the flow of the air and water at the outlet (into the atmosphere) of the two pipes was measured. Each drill stem having identical conditions for the fluid exiting the pipe and identical supply (r.p.m. of the compressor motor, and initial pressures of the air and of the water).

Using the LIHR type *ddr*, with air as the fluid, an increase of the outflow velocity (and thus of overall flow) was measured at:

$\Delta \mathbf{v}_c\% = \Delta \mathbf{Q}\% = +10.0\%$

and an increase in the useful kinetic energy of the fluid equal to:

$\Delta \mathbf{E}_c\% = +21.0\%$

whereas with the water, the increases measured, using the LIHR type *ddr*, were:

Outflow velocity and flow: $\Delta \mathbf{v}_c\% = \Delta \mathbf{Q}\% = +10.5\%$

Kinetic energy of fluid: $\Delta \mathbf{E}_c = +22.0\%$

The velocity of the outflow of air was measured using a simple device (fig.4) which was comprised of a fan linked to the shaft of an electric motor that was turned by the action of the flow of air on the fan. The voltage produced by the motor was proportional to the flow of air. Obviously, the nozzle and fan had the same geometry for each type of tested *ddr* (LIHR and X-series).

For the experiment with water, an even simpler method was used. What was measured in this case was the distance travelled by the water jet leaving the pipe using a nozzle fixed to each rod in turn (fig. 5). To calculate the exit velocity of the water, a formula was applied the validity of which depends on the following conditions: Low outflow velocity; Low pressure; Compact water jet; and small distance of water jet.

In these conditions, the error in measuring was ± 1 cm. The results were obtained as anticipated from two drill stems 60 m long.

Using simple energy considerations, the results obtained can be extrapolated for the general case.

Considering two drill stems of equal length: $\mathbf{L}_T = \mathbf{n} \cdot \mathbf{s}_a$ (where **n** is the number of rods and $\mathbf{s}_a$ the length of a single rod) being perfectly aligned and horizontal. If we call **H** the initial energy of the fluid that enters each of the drill stem, at the exit of the fluid from the drill stem some of the energy will have been converted into kinetic energy of the fluid (that we can express, cancelling out the specific mass term of the fluid, as $\mathbf{E}_c = \mathbf{v}_c^2/2\mathbf{g}$). Another part of the energy will have been used to overcome the resistance to motion inside the tube. If we call the energy lost (expressed again cancelling out the specific mass term) E_L then will be equal to the sum of two factors: The energy lost due to the resistance present of the friction of the tube walls: $H_p=L_p \cdot E_p$. Using the principle of conservation of mass, this energy can be expressed, once the geometry of the tube and the roughness of the tube walls have been defined, as a function of the exit velocity: $H_p=L_p k v_c^2$ (with **k** being constant and L_p the complete length of the drill stem excluding connections); and the energy lost due to the localised resistance from each of the **n** connections between rods. Again, applying the conservation of mass, this loss can be expressed, once the geometry of the pipes has been established, as a function of the exit velocity v_c: $H_C=n \cdot k_c v_c^2$.

We can write: $H=E_c+H_p+H_C$ [1]

As has already been seen, the terms in equation [1] above can all be expressed in terms of the exit velocity v_2 and the number of sections **n** in the drill stem (once the geometry of the tube, roughness of the tube walls and initial energy **H** have been defined):

$$H = v_c^2\left(\frac{1}{2g} + L_P k + n \cdot k_c\right) \quad [2]$$

If equation [2] is written for each of the tested drill stem, we have:

$$\begin{cases} H = v_{c1}^2(\xi + n \cdot k_{c1}) \\ H = v_{c2}^2(\xi + n \cdot k_{c2}) \end{cases} \quad [3]$$

where: $\xi = \frac{1}{2g} + L_P k$

Combining these equations [3], the ratio of the velocities squared becomes:

$$\delta(n) = \frac{v_{c2}^2}{v_{c1}^2} = \frac{\xi + k_{c1} n}{\xi + k_{c2} n} \quad [4]$$

where k_{c1} and k_{c2} are physical-geometrical coefficients related to the hydraulic resistance in the connections between rods. From [4] above we can get:

$$\Delta E_c = \frac{k_{c2} - k_{c1}}{\xi + k_{c1} n} n \quad [5]$$

This equation represents the way the increase in kinetic energy varies with the number of rods, **n**.

Applying [4] and [5] to the case in question, if v_{c1} and k_{c1} represent respectively the exit velocity and the coefficient of hydraulic resistance of the single connections for the LIHR assembly and similary v_{c2} and k_{c2} for the X-series assembly, it is easy to show that for equal initial conditions, with an increase in the number of rods **n** the ratio of the squares of velocity tend to a value equal to the ratio of the coefficients that express the hydraulic resistance of the connections between rods:

$$\frac{v_{c2}^2}{v_{c1}^2} = \frac{k_{c1}}{k_{c2}} \quad \text{where } n \text{ is very large} \quad [6]$$

On a practical level, this means that reducing the hydraulic resistance of the connections between rods (awhere all other factors are equal) gives a greater useful energy. The minimum increase in useful energy that is possible is (as a percentage) equal to:

$$\Delta E_{c\min}\% = \frac{k_{c2} - k_{c1}}{k_{c1}} \cdot 100\% \quad [7]$$

CONCLUSION.

Thanks to the use of special steels, an innovative welding technique and the careful design and testing of the product, it has been possible to produce a *ddr* that combines high mechanical performance with the possibility of the reduction of drilling times and costs that the lower hydraulic resistance of this *ddr* allows. Simple and easily reproducible tests and a qualitative analysis of the energy considerations pertinent to this application show that the gains in energy possible can be considerable. Colli Drill Pipe DDR LIHR is available in 5 different outside diameters: 38, 48, 60.3, 76.1 and 88.9 mm and lengths from 0.6 to 6.0 m.

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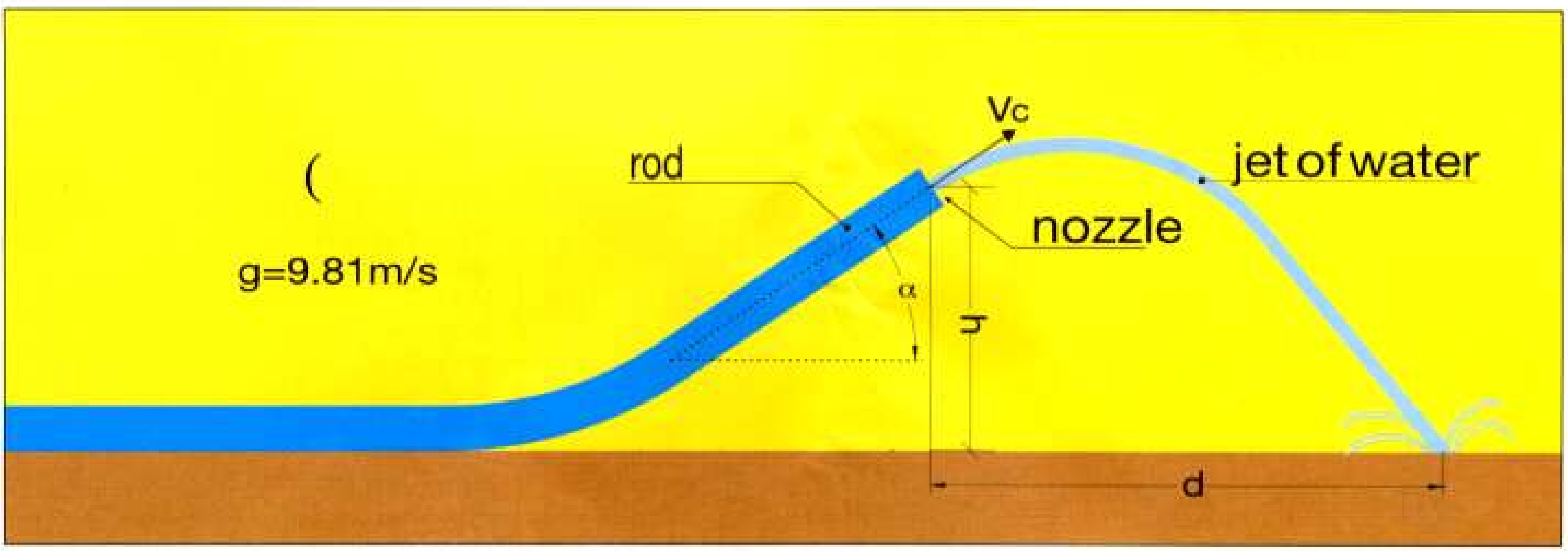

Figure 5.