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Cuban methodology for estimating the efficiency of rotodynamic pumping equipment

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Abstract: The updated procedure for estimating the minimum or reference efficiency of rotodynamic pumping equipment, which is part of Resolution No. 655/2009 of the Ministry of Construction (Micons), is a vital contribution for specialists responsible for selecting rotodynamic pumping equipment in the country. This improved version incorporates technical criteria for selecting efficiently designed rotodynamic pumps, which can be used during the preliminary design phase of requesting proposals for this equipment. One of the added aspects is the operational efficiency criterion for rotodynamic pumps, based on three reference efficiency points (75%, 100%, and 110% of the dimensionless design flow rate) as a function of the specific speed, establishing the references to be used for calculating the dimensionless efficiency at these points. To this end, several international reference models were analyzed to obtain dimensionless efficiency values for rotodynamic pumps, with the aim of determining the equations for estimating this efficiency for operational efficiency values. An updated methodology was developed for selecting the most efficient rotodynamic pumping equipment available on the market.

Key words: methodology; estimation; efficiency; pumping equipment; rotodynamics

1 Introduction

It is well known that improper selection of pumping equipment leads to equipment malfunction, affecting its efficiency and that of the pumping system as a whole. This results in increased energy consumption, maintenance, and operating costs, which has become a global problem in pumping system management. The creation of regulations regarding the selection of rotodynamic pumps, taking their efficiency into account, has been one of several alternatives that have emerged to address these issues (Martínez 2011).

Law No. 124/14 on Terrestrial Waters establishes in Article 4, Section d), that the National Institute of Hydraulic Resources (INRH), as an agency of the Central State Administration responsible for the management of terrestrial waters, is responsible for issuing and monitoring the application of hydraulic regulations related to terrestrial waters. Article 3.1, Section e), also establishes, as one of the principles governing the integrated and sustainable management of terrestrial waters, their rational use and reuse. As a complementary legal norm, Decree 337, *Regulations of Law 124 on Terrestrial Waters*, in Article 93, in relation to Article 91, Section g), empowers the National Institute of Hydraulic Resources to issue hydraulic regulations on the technical parameters and efficiency of machinery, hydraulic equipment, fixtures, and sanitary fittings (Minjus 2017).

Resolution No. 655/2009, *Standard for Water Consumption in Pumping Equipment, Accessories, and Plumbing*

Fixtures, issued by the Cuban Ministry of Construction (Micons), was published on November 19, 2009, in Official Gazette No. 49 (Minjus 2009). This resolution repealed Resolution No. 28 of the National Institute of Hydraulic Resources (INRH), which had been in effect since 2006 and was enacted during the Energy Revolution. The current resolution was conceived to address the need for measures that would contribute to the acquisition or domestic production of water-efficient equipment, accessories, plumbing fixtures, and high-quality, energy-efficient electric pumps. The aforementioned resolution was issued during the validity of the repealed Decree Law No. 245 by which the INRH was attached to the Ministry of Construction, and it is the power in the present of the aforementioned Institute to regulate the aspects provided for in the aforementioned Resolution (Martínez and Hernández 2019).

Annex 1 of this resolution establishes the maximum permissible energy consumption of the devices addressed in the regulatory document. Annex 2, on the other hand, refers to the minimum energy efficiency values that rotodynamic pumping equipment must meet. It addresses the minimum reference values for both single-phase and three-phase electric motors (submersible or not) as well as for rotodynamic pumps. Annex 3 is dedicated to the procedure for requesting and obtaining approval for the import or domestic production of pumping equipment. While this regulatory guidance document is the first of its kind in the country aimed at the appropriate selection of rotodynamic pumps from an efficiency standpoint, its correct application has faced several setbacks and, at times, certain deficiencies in its implementation across various productive sectors of the country (Martínez 2019).

This paper presents a proposed update to Resolution No. 655/2009, based on current national and international regulations for estimating the efficiency of rotodynamic pumping equipment. It considers all the hydraulic design variables of this equipment, as well as other technical and economic factors, to ensure that equipment imported into the country is selected based on its optimal efficiency. Furthermore, it can serve as a benchmark for the minimum efficiency values required for domestically manufactured pumps.

2 Development

Given the high energy consumption of rotodynamic pumping equipment in our country (27-30% of the country's energy generation), it is imperative to delve deeper into the studies and analyses of the various methodologies used worldwide to estimate the efficiency of pumping equipment. This is of vital importance, as it has immediate application in the selection process for both imported and domestically manufactured pumping equipment, serving as indicative references for the latter (Martínez and Hernández 2019). Therefore, the main objective of this nationally important work is to develop updated regulations for estimating the minimum or reference efficiency of rotodynamic pumping equipment intended for operation in the country.

Resolution No. 655/2009 has presented several technical limitations in its content and application since its implementation, hindering its effective use for the proper selection of efficient rotodynamic pumping equipment, in line with new international trends on the subject. Addressing these technical limitations of the aforementioned regulation and finding solutions have been the subject of several research projects at the Center for Hydraulic Research (CIH) for almost two decades.

Therefore, based on the experience gained from the application of Resolution No. 655/2009 and with a view to contributing to the integrated and sustainable management of inland waters and energy efficiency, it is necessary to establish permissible consumption standards for major water-consuming plumbing fixtures and fittings, as well as minimum or reference values for evaluating the energy efficiency of electric pumps and the requirement, prior to their importation by the supplier, of the corresponding certification attesting to the required qualities (Martínez and Hernández 2019).

2.1 Estimation of the efficiency of rotodynamic pumps

From the well-known Wislicenus chart published in 1947 to the more recent charts and equations developed by the American Institute of Hydraulics (HI) in conjunction with the National Standards Institute of the United States (ANSI-HI) (HI 2015), the Europump Association (EUROPUMP 2012), and the UK's BPMA (OJEU 2012)—to name just the most important references—these have become invaluable tools for estimating the efficiency of rotodynamic pumps. Although several standards exist worldwide for this purpose, those mentioned above are the most accurate and internationally recognized. These take into account the specific speed and the limits of deviation from efficiency that could be influenced by the following design factors: product quality, shape of the chosen curve, surface roughness, internal clearances, manufacturing compromises, mechanical losses, capacity for handling dissolved solids and tolerance in testing (Martínez 2009).

In addition to these elements, which generally correspond to the manufacturing of the pumping equipment, there are other factors that negatively affect efficiency and have an impact from an operational standpoint. Among the main ones, the following can be noted: volumetric losses, hydraulic losses, mechanical losses, characteristics of the liquid being pumped, installation conditions, impeller trimming, operational considerations, aquifer characteristics (for these source systems), and oversizing of the installation in general (Martínez 2009).

There are two methods for estimating the efficiency of rotodynamic pumps: the component method and the overall efficiency method. The component method is based on determining the individual efficiencies that represent the losses occurring during pump operation. It is expressed by the following equation (Martínez 2019):

$$\eta_b = \eta_h \cdot \eta_v \cdot \eta_m \cdot \eta_{sf} \qquad (1)$$

Where: η_b: total pump efficiency, (dimensionless); η_v: volumetric pump efficiency, (dimensionless); η_h: hydraulic pump efficiency, (dimensionless); ηm: mechanical pump efficiency, (dimensionless) and ηsf: friction efficiency in the disc (some references include it as a subcomponent of the mechanical efficiency), (dimensionless).

The overall efficiency method, as its name suggests, is based on the overall efficiency of the pump. This method is divided into two steps: first, the maximum expected efficiency of the pump is calculated, which depends exclusively on its design flow rate. In the second step, the pump's reference efficiency is determined, taking into account a correction coefficient that is a function of the specific speed. Finally, the acceptable range of pump efficiency is established (the statistical range within which the equipment's efficiency must fall to be selected) (Martínez and Hernández, 2019).

For this study to update the aforementioned standard, a sample of more than 3,000 rotodynamic pumps was used, which were classified according to the following design groups: horizontal mounted rotodynamic pumps with volute-type casing for clean water; horizontal and vertical mounted multistage rotodynamic pumps, submersible or not, with ring-type casing for clean water; vertical mounted multistage submersible rotodynamic pumps with bowl-type casing for clean water; horizontal mounted double-suction (split-case) rotodynamic pumps for clean water; horizontal and vertical mounted rotodynamic pumps for wastewater; and horizontal and vertical mounted dewatering rotodynamic pumps.

The selection of equipment for the study sample (conventional, mass-produced equipment without special designs) comes from approximately twenty international manufacturers that have entered the country to date, although it also includes equipment that may be imported in the future. The data obtained for each pumping unit includes: rotation speed, efficiency and flow rate values for three reference points (75%, 100%, and 110% of the design flow rate), design head, number of stages, number of suction inlets, and other specific data of interest.)

This work analyzes the fundamental concepts related to pumping equipment efficiency and the main factors that influence it. A comprehensive study of current international standards was conducted to estimate the minimum efficiency levels that such equipment must meet. Operational efficiency verification criteria were introduced for partial load (PL) and overload (OL) points, η_{OLr}. The specific speed range for ring-type case pumps and dewatering pumps was expanded. Reference efficiency values for double-suction pumps, which were not included in the aforementioned resolution (Álvarez 2022), are also presented. For electric motors, the nominal operating power range was expanded, and the minimum expected efficiency values for classes IE2 and IE3 were updated (IEC 2020).

Furthermore, a critical review of Micons Resolution No. 655/2009 was conducted, describing its main conceptual limitations, numerical errors, and calculation procedures, as well as its implementation approach, and proposing an update. An expansion and a new distribution by design type for rotodynamic pumps were also carried out, proposing new, more precise values for their minimum efficiency (Álvarez 2022).

One of the novel and, moreover, one of the most important aspects incorporated in this update is the redefinition of the concept of the optimal specific speed range according to the pump design type. This new approach was proposed by the authors in Martínez (2011), where this new concept first appeared, resulting from a statistical study differentiated by design groups, using a sample of more than 2,500 pumps. Several subsequent investigations reinforced this hypothesis regarding the optimal Nq values and their associated range. In this study, after a statistical validation process of the study sample, this concept was confirmed once again, now coinciding with the findings published by HI (2015). It is then defined that the optimal specific speed range for volute and ring-type pumps is 35 to 65, while for bowl-type pumps, it is between 85 and 115. In this sense, the optimal values are assumed to be 50 and 95, respectively.

The following is a proposed methodology for estimating the efficiency of rotodynamic pumping equipment.

Proposal for updating Resolution No. 655/2009 of the National Institute of Hydraulic Resources (INRH) for estimating the efficiency of rotodynamic pumping equipment.

Resolution No. X/2023: Minimum efficiency values for rotodynamic electric pumps.

Aspects to consider for estimating the efficiency of the pump-motor assembly.

Object and scope of application:

1. This annex establishes the requirements for the marketing and importation of rotodynamic pumps for pumping clean water and wastewater.

2. This annex shall not apply to:

a) Rotodynamic pumps specifically designed to pump clean water at temperatures below -10°C or above 120°C

b) Direct-coupled, axial-suction, in-line rotodynamic pumps (in-line pumps)

c) Self-priming rotodynamic pumps

d) Other types of rotodynamic pumps with special designs to meet specific application requirements.

3 Definitions

The specific speed, Nq, is a design parameter of rotodynamic pumps and is mathematically expressed as:

$$N_q = \frac{n \cdot \sqrt{Q_{do}}}{H_{di}^{0,75}} \qquad (2)$$

Where: *Nq*: specific speed, (dim.); n: nominal rotation speed of the rotodynamic pump, (rpm); *Qdo*: design flow rate per eye or impeller inlet, (m^3/s) and *Hdi*: design head per stage *i*, (m).

The optimum value of the specific speed is in the vicinity of 50 for rotodynamic pumps with volute and ring type casings, while for those with bowl type casings it will be around 95.

The following conventional, standardized and normalized rotodynamic pump designs are analyzed in this annex, with nominal working speeds of approximately 1,160, 1,750 and 3,500 rpm (corresponding to six, four and two pole electric motors respectively):

a. Horizontally mounted rotodynamic pumps with volute casing for clean water

b. Horizontally and vertically mounted multistage rotodynamic pumps, submersible or not, with ring casing for clean water

c. Vertically mounted multistage submersible rotodynamic pumps with bowl casing for clean water

d. Horizontally mounted double-suction (split-case) rotodynamic pumps for clean water

e. Horizontally and vertically mounted rotodynamic pumps for wastewater

f. Horizontally and vertically mounted dewatering rotodynamic pumps.

• Horizontally mounted rotodynamic pumps with volute casing for clean water use: single-stage, axially suction rotodynamic pumps with their own bearings and stuffing boxes, designed for pressures up to 16 bar. This group of pumps also includes monobloc pumps (those in which the motor shaft has been extended to also serve as the pump shaft). The operating limits for specific speed and design flow rate are those established in Table 3.

• Horizontal and vertical multistage rotodynamic pumps, submersible or not, with ring-type casing for clean water use: rotodynamic pumps with multistage stuffing boxes ($1 \leq i \leq 7$), whose impellers are mounted on a rotating horizontal or vertical shaft designed for pressures up to 25 bar. The operating limits in terms of specific speed and design flow rate are those established in Table 4.

• Vertically mounted, multi-stage, submersible, bowl-type rotodynamic pumps for clean water: Multi-stage rotodynamic pumps ($1 \leq i \leq 12$) whose impellers are mounted on a rotating vertical shaft designed for pressures up to 25 bar, with a nominal outside diameter of 4″ (10.16 cm) or more, designed for operation in a well. The operating limits for specific speed and design flow rate are those established in Table 5.

• Horizontally mounted, double-suction (split-case) rotodynamic pumps for clean water: axially suction rotodynamic pumps with a closed, double-suction impeller and an axially split casing with opposing, horizontal suction and discharge flanges located on the lower body. The operating limits for specific speed and design flow rate are those established in Table 6.

• Horizontal and vertical mounted rotodynamic pumps for wastewater treatment: single-stage axial suction rotodynamic pumps equipped with their own bearings and stuffing boxes, with a specific design that allows them to operate with contaminated water and suspended solids. The operating limits in terms of specific speed and design flow rate are those established in Table 7.

• Horizontal and vertical mounted rotodynamic dewatering pumps: Single-stage or multi-stage axial suction rotodynamic pumps equipped with their own bearings and stuffing boxes, with a specific design that allows them to operate with water containing suspended solids. Two types of design are available: stainless steel pumps and plastic pumps. The former can pump liquids at a maximum temperature of 40°C and can be submerged to a maximum depth of eight meters; while the latter can be submerged to a depth of five meters and withstand temperatures up to 35°C. The operating limits in terms of specific speed and design flow rate are those established in Table 8.

• Clean water: water with a maximum free and non-absorbent solids content of 0.25 kg/m^3 and a maximum dissolved solids content of 50 kg/m^3, provided that the total gas content in the water does not exceed the saturation volume. Hydraulic pumps will be considered to operate with clean water at ambient temperature ($T \leq 40°C$) with the following properties: maximum kinematic viscosity: 1.5×10^{-6} m^2/s and maximum density: 1,050 kg/m^3.

• Wastewater: water with fecal contents, wash water, solid substances and different remains of inorganic and organic nature with contents of dissolved and free and non-absorbent solids higher than the maximums established for clean water.

Procedure for estimating the efficiency of rotodynamic pumping equipment

It is considered that a rotodynamic pumping unit has acceptable efficiency when the efficiency value of the pump-motor combination η_{eb}, is greater than that obtained by the following equation:

$$\eta_{eb} > \eta_{rb} \cdot \eta_{rm} \quad (3)$$

Where: η_{eb}: quoted or catalog efficiency of the rotodynamic electric pump (information provided by the manufacturer), expressed as a percent (%); η_{rb}: reference or minimum required efficiency of the rotodynamic pump based on the specific speed and design flow rate, equivalent to the pump's design point efficiency, η_{BEP} (see tables 3-8), expressed as a percent (%); and η_{rm}: reference or minimum required efficiency of the motor based on its rated power, working speed, and design type (submersible or not), equivalent to the maximum efficiency for its nominal design load (see tables 1 and 2), expressed as a percent (%).

Guidelines to keep in mind for the process:

- The reference or minimum required efficiency of the rotodynamic pump for the pump design point, η_{BEP}, according to the values defined in tables 3 to 8, is determined based on the flow rate and specific speed corresponding to the point of maximum performance (BEP) for the full diameter of the impeller and with clean water at room temperature.
- Tables 1 and 2 show the minimum reference values for electric motors in the high efficiency (IE2) and premium efficiency (IE3) categories. The tabulated values correspond to conventional three-phase, single-speed squirrel-cage induction motors for a frequency of 60 Hz.
- It is accepted that obtaining intermediate efficiency values for rotodynamic pumps in the reference tables is done by simple or double linear interpolations (when the design flow rate and specific speed do not appear in the table).
- Values outside the established flow rate and specific velocity ranges in the tables should not be extrapolated.

Additional considerations (not binding on the procedure):

- It is recommended that the catalog efficiency values for both the motor and the rotodynamic pumps exceed those specified in their respective reference tables (Tables 1-8). It is clear that by fulfilling the requirements in this section, equation (3), which serves as a kind of basic requirement for selecting the most efficient rotodynamic pumping equipment, is satisfied.
- It is advisable to review the performance requirements for partial load (PL) (pump operating point at 75% of the design flow rate), PLr, and overload (OL) (pump operating point at 110% of the design flow rate), OLr. The efficiency values for the pump being analyzed must be higher than those calculated using equations 4 and 5 or 6 and 7, depending on the pump design type, except for horizontal and vertical rotodynamic pumps used for wastewater and drainage applications. This analysis is only relevant if the pump's design efficiency (catalog) exceeds the minimum or reference efficiency (tables). Therefore, to ensure a better selection of the rotodynamic pump, the three reference values for operational efficiency (75%, 100%, and 110%) must meet this condition.
- Horizontal mounted rotodynamic pumps with volute-type casing and double suction (split chamber) for working with clean water ($10 \leq Nq \leq 80$):

$$\eta_{PLr} = 0{,}945 \cdot \eta_{rb} = 0{,}945 \cdot \eta_{BEP} \quad (4)$$

$$\eta_{OLr} = 0{,}99 \cdot \eta_{rb} = 0{,}99 \cdot \eta_{BEP} \quad (5)$$

- Horizontal and vertical multistage rotodynamic pumps, submersible or not, with ring or bowl type casing for use with clean water ($10 \leq Nq \leq 100$):

$$\eta_{PLr} = 0{,}947 \cdot \eta_{rb} = 0{,}947 \cdot \eta_{BEP} \quad (6)$$

$$\eta_{OLr} = 0{,}99 \cdot \eta_{rb} = 0{,}99 \cdot \eta_{BEP} \qquad (7)$$

• The acceptable range of the reference efficiency of rotodynamic pumps, Δ, can be used as a criterion for selecting the most efficient pumps on the market, which will be those with efficiencies within this range. This interval is established by the following expression:

$$\Delta\eta = \eta_{rb} \div \left(1+\frac{r}{100}\right) \cdot \eta_{rb} \qquad (8)$$

Where: $\Delta\eta$: range of acceptance of the reference efficiency of the rotodynamic pumps, (%); η_{rb}: reference or minimum required efficiency of the rotodynamic pump as a function of the specific speed and design flow rate (see tables 3-8) and r: range of possible deviation from the reference efficiency of the rotodynamic pumps, (%).

The possible deviation range from the reference efficiency of rotodynamic pumps, r, depends on the pump's design flow rate and is defined for the flow rate range from 2 to 2,778 L/s by the equation:

$$r = \frac{18{,}858}{Q_{do}^{0{,}348}} \qquad (9)$$

Where: r: possible deviation range from the reference efficiency of the rotodynamic pumps, (%) and Q_{do}: design flow rate per eye or impeller inlet, (L/s).

• It is worth clarifying that there are rotodynamic pumps on the market with efficiencies higher than the maximum value established by the acceptance range of the reference efficiency of rotodynamic pumps for each type of design, which represent 20% of the representative samples taken for these studies.

• The maximum efficiency values for both rotodynamic pumps and electric motors are presented as a benchmark — an achievable and even surpassable target. Using rotodynamic pumping equipment with a higher percentage efficiency than other, potentially cheaper, equipment can offset the higher initial cost of the more efficient option.

• In all cases, the technical solution for pumping should consider selecting rotodynamic pumps with specific speed values between 35 and 65 for volute and ring-type pumps, and between 85 and 115 for bowl-type pumps, with the optimum values being 50 and 95 respectively. If a different type of equipment is proposed, a corresponding economic feasibility study must be submitted.

Table 1. Minimum efficiency of non-submersible electric motors

Nominal power P (kW)	**2 poles**		**4 poles**		**6 poles**	
	η_{min} (IE2) (%)	**η_{min} (IE3) (%)**	**η_{min} (IE2) (%)**	**η_{min} (IE3) (%)**	**η_{min} (IE2) (%)**	**η_{min} (IE3) (%)**
0,75	75,5	77,0	82,5	85,5	80,0	82,5
1,1	82,5	84,0	84,0	86,5	85,5	87,5
1,5	84,0	85,5	84,0	86,5	86,5	88,5
2,2	85,5	86,5	87,5	89,5	87,5	89,5
3,7	87,5	88,5	87,5	89,5	87,5	89,5
5,5	88,5	89,5	89,5	91,7	89,5	91,0
7,5	89,5	90,2	89,5	91,7	89,5	91,0
11	90,2	91,0	91,0	92,4	90,2	91,7
15	90,2	91,0	91,0	93,0	90,2	91,7
18,5	91,0	91,7	92,4	93,6	91,7	93,0
22	91,0	91,7	92,4	93,6	91,7	93,0
30	91,7	92,4	93,0	94,1	93,0	94,1
37	92,4	93,0	93,0	94,5	93,0	94,1
45	93,0	93,6	93,6	95,0	93,6	94,5
55	93,0	93,6	94,1	95,4	93,6	94,5
75	93,6	94,1	94,5	95,4	94,1	95,0
90	94,5	95,0	94,5	95,4	94,1	95,0

110	94,5	95,0	95,0	95,8	95,5	95,8
150	95,6	96,1	95,7	96,5	95,4	96,0
185	96,1	96,6	96,2	96,9	95,9	96,4
340	97,6	97,8	97,4	98,0	97,3	97,6
375	97,8	98,0	97,6	98,2	97,5	95,8

Table 2. Minimum efficiency of submersible electric motors

Nominal power *P* (kW)	**2 poles**		**4 poles**		**6 poles**	
	η_{min} (IE2) (%)	**η_{min} (IE3) (%)**	**η_{min} (IE2) (%)**	**η_{min} (IE3) (%)**	**η_{min} (IE2) (%)**	**η_{min} (IE3) (%)**
0,75	62,4	72,3	77,3	80,2	70,0	77,5
1,1	64,7	73,8	77,2	80,4	71,6	78,3
1,5	66,5	75,0	77,3	80,5	72,8	79,0
2,2	68,7	76,5	77,6	80,7	74,3	79,8
3,7	71,5	78,4	77,9	81,1	76,2	81,0
5,5	73,6	79,9	78,3	81,4	77,7	81,9
7,5	75,2	80,9	78,6	81,8	78,8	82,7
11	77,1	82,3	79,1	82,3	80,2	83,6
15	78,7	83,4	79,6	82,7	81,2	84,3
18,5	79,7	84,1	80,0	83,1	81,9	84,9
22	80,5	84,7	80,4	83,4	82,6	85,3
30	81,9	85,8	81,1	84,1	83,6	86,1
37	82,9	86,5	81,6	84,6	84,3	86,6
45	83,8	87,1	82,2	85,2	85,0	87,1
55	84,7	87,8	82,9	85,8	85,7	87,7
75	86,1	88,8	84,1	86,9	86,7	88,5
90	86,9	89,4	84,9	87,6	87,3	89,0
110	87,8	90,0	85,9	88,5	87,9	89,6
150	89,2	91,0	87,8	90,1	88,9	90,4
185	90,1	91,7	89,3	91,4	89,6	91,0
340	92,6	93,6	95,1	96,0	91,5	92,8
375	93,0	93,9	96,3	96,9	91,8	93,1

Table 3. Minimum efficiency values for horizontal mounted rotodynamic pumps with volute-type casing for clean water operation

Q_{do} (L/s)	**N_q**										
	10	20	30	40	50	60	70	80	90	100	110
0,6	25,5	44,5	50,6	52,6	52,8	52,1	51,0	49,5	47,9	46,2	44,4
0,7	27,2	46,2	52,2	54,2	54,4	53,7	52,6	51,1	49,5	47,8	46,0
0,8	28,7	47,6	53,6	55,6	55,8	55,1	53,9	52,5	50,8	49,1	47,3
0,9	29,9	48,8	54,8	56,8	56,9	56,3	55,1	53,6	52,0	50,3	48,5
1	31,0	49,9	55,9	57,8	58,0	57,3	56,1	54,6	53,0	51,3	49,5
2	37,8	56,5	62,4	64,2	64,3	63,6	62,4	60,9	59,2	57,5	55,6
3	41,4	60,0	65,8	67,6	67,7	66,9	65,7	64,1	62,5	60,7	58,9
4	43,8	62,3	68,0	69,8	69,9	69,1	67,8	66,3	64,6	62,8	61,0
5	45,5	64,0	69,7	71,4	71,5	70,7	69,4	67,9	66,2	64,4	62,5
6	46,9	65,3	71,0	72,7	72,8	71,9	70,6	69,1	67,4	65,6	63,7
7	48,0	66,4	72,0	73,7	73,8	72,9	71,6	70,1	68,4	66,6	64,7
8	48,9	67,3	72,9	74,6	74,6	73,8	72,5	70,9	69,2	67,4	65,5
9	49,7	68,0	73,6	75,3	75,3	74,5	73,2	71,6	69,9	68,1	66,2
10	42,2	50,4	68,7	74,3	76,0	76,0	75,1	73,8	72,2	70,5	68,7
20	46,3	54,5	72,6	78,1	79,7	79,6	78,7	77,4	75,7	74,0	72,1
30	48,3	56,5	74,5	79,9	81,5	81,4	80,5	79,1	77,4	75,7	73,8
40	49,6	57,8	75,7	81,1	82,6	82,5	81,5	80,1	78,5	76,7	74,8
50	50,5	58,6	76,5	81,8	83,4	83,2	82,2	80,8	79,2	77,4	75,5
60	51,2	59,3	77,1	82,4	83,9	83,8	82,8	81,4	79,7	77,9	76,0
70	51,7	59,8	77,6	82,9	84,3	84,2	83,2	81,7	80,1	78,2	76,3
80	52,1	60,2	78,0	83,2	84,7	84,5	83,5	82,1	80,4	78,5	76,6
90	60,5	78,3	83,5	85,0	84,8	83,8	82,3	80,6	78,8	76,9	74,9
100	60,8	78,5	83,7	85,2	85,0	84,0	82,5	80,8	79,0	77,1	75,1
200	62,2	79,7	84,8	86,2	85,9	84,9	83,4	81,6	79,8	77,8	75,8
300	62,6	80,0	85,1	86,4	86,1	85,0	83,5	81,7	79,9	77,9	75,9
400	62,7	80,1	85,1	86,4	86,1	84,9	83,4	81,6	79,7	77,8	75,8
500	62,8	80,0	85,0	86,3	85,9	84,8	83,3	81,5	79,6	77,6	75,6
600	62,7	79,9	84,9	86,1	85,8	84,6	83,1	81,3	79,4	77,4	75,4
700	62,6	79,8	84,7	85,9	85,6	84,4	82,9	81,1	79,1	77,1	75,1

800	62,5	79,6	84,6	85,8	85,4	84,2	82,6	80,8	78,9	76,9	74,9
900	62,4	79,5	84,4	85,6	85,2	84,0	82,4	80,6	78,7	76,7	74,7
1,000	62,2	79,3	84,2	85,4	85,0	83,8	82,2	80,4	78,5	76,5	74,4
2,000	60,9	77,8	82,6	83,7	83,2	82,0	80,4	78,5	76,6	74,5	72,5

Table 4. Minimum efficiency values for horizontal and vertical multistage rotodynamic pumps, submersible or not, with ring-type casing for use with clean water

Q_{do} (L/s)	N_q									
	10	20	30	40	50	60	70	80	90	100
0,6	72,3	72,2	72,4	72,7	72,9	72,9	72,7	72,3	71,9	71,3
0,7	72,4	72,3	72,5	72,8	73,0	73,0	72,8	72,4	72,0	71,4
0,8	72,5	72,5	72,6	72,9	73,1	73,1	72,9	72,5	72,1	71,6
0,9	72,6	72,7	72,8	73,1	73,3	73,3	73,1	72,7	72,3	71,7
1	72,7	73,2	73,5	73,6	73,5	73,4	73,2	72,9	72,4	71,9
2	73,2	74,1	74,7	75,1	75,2	75,1	74,9	74,6	74,1	73,6
3	73,8	75,0	75,9	76,4	76,6	76,6	76,3	76,0	75,5	75,0
4	74,4	75,8	76,8	77,4	77,7	77,7	77,5	77,1	76,7	76,2
5	76,2	77,3	78,0	78,5	78,7	78,7	78,5	78,1	77,7	77,1
6	76,8	77,9	78,8	79,3	79,5	79,5	79,3	79,0	78,5	78,0
7	77,8	78,9	79,6	80,1	80,3	80,3	80,1	79,7	79,3	78,7
8	78,2	79,5	80,3	80,8	81,0	81,0	80,7	80,4	79,9	79,4
9	78,4	80,0	80,8	81,1	81,1	79,9	79,4	79,0	78,4	77,9
10	78,5	80,1	81,0	81,2	81,3	80,1	79,7	79,2	78,7	78,1
20	78,8	80,7	81,7	82,0	82,0	81,7	81,3	80,8	80,3	79,7

Table 5. Minimum efficiency values for vertically mounted multi-cell submersible rotodynamic pumps with bowl-type casing for use with clean water.

Q_{do} (L/s)	N_q												
	10	20	30	40	50	60	70	80	90	100	110	120	130
0,3	15,3	34,5	40,7	42,7	43,0	42,4	41,3	39,9	38,3	36,6	34,9	33,1	31,3
0,4	18,8	38,0	44,0	46,1	46,3	45,7	44,6	43,2	41,6	39,9	38,1	36,3	34,6
0,5	21,4	40,5	46,6	48,6	48,8	48,2	47,0	45,6	44,0	42,3	40,5	38,8	37,0
0,6	23,5	42,6	48,6	50,6	50,8	50,1	49,0	47,6	45,9	44,2	42,5	40,7	38,9
0,7	25,2	44,2	50,2	52,2	52,4	51,8	50,6	49,1	47,5	45,8	44,0	42,2	40,4
0,8	26,7	45,7	51,6	53,6	53,8	53,1	52,0	50,5	48,9	47,2	45,4	43,6	41,8
0,9	28,0	46,9	52,8	54,8	55,0	54,3	53,1	51,7	50,0	48,3	46,5	44,7	42,9
1	29,1	48,0	53,9	55,8	56,0	55,3	54,2	52,7	51,1	49,3	47,5	45,7	43,9
2	35,9	54,6	60,4	62,3	62,4	61,7	60,4	58,9	57,3	55,5	53,7	51,9	50,0
3	39,5	58,1	63,9	65,7	65,8	65,0	63,7	62,2	60,5	58,8	56,9	55,1	53,2
4	41,9	60,4	66,1	67,9	68,0	67,2	65,9	64,4	62,7	60,9	59,1	57,2	55,4
5	43,6	62,1	67,8	69,5	69,6	68,8	67,5	66,0	64,3	62,5	60,6	58,8	56,9
6	45,0	63,4	69,1	70,8	70,9	70,0	68,7	67,2	65,5	63,7	61,8	60,0	58,1
7	46,1	64,5	70,1	71,8	71,9	71,0	69,7	68,2	66,5	64,7	62,8	60,9	59,0
8	47,0	65,4	71,0	72,7	72,7	71,9	70,6	69,0	67,3	65,5	63,6	61,7	59,8
9	47,8	66,1	71,8	73,4	73,5	72,6	71,3	69,7	68,0	66,2	64,3	62,4	60,5
10	48,5	66,8	72,4	74,1	74,1	73,2	71,9	70,3	68,6	66,8	64,9	63,0	61,1
20	52,6	70,7	76,2	77,8	77,7	76,8	75,5	73,9	72,1	70,3	68,4	66,4	64,5
30	54,6	72,6	78,1	79,6	79,5	78,6	77,2	75,6	73,8	71,9	70,0	68,1	66,2
40	55,9	73,8	79,2	80,7	80,6	79,6	78,3	76,6	74,8	72,9	71,0	69,1	67,1
50	56,8	74,6	80,0	81,5	81,3	80,4	79,0	77,3	75,5	73,6	71,7	69,7	67,8
60	57,4	75,2	80,6	82,0	81,9	80,9	79,5	77,8	76,0	74,1	72,2	70,2	68,3
70	57,9	75,7	81,0	82,5	82,3	81,3	79,9	78,2	76,4	74,5	72,5	70,6	68,6
80	58,3	76,1	81,4	82,8	82,6	81,6	80,2	78,5	76,7	74,8	72,8	70,9	68,9
90	58,7	76,4	81,7	83,1	82,9	81,9	80,4	78,8	76,9	75,0	73,1	71,1	69,1
100	59,0	76,7	81,9	83,3	83,1	82,1	80,6	78,9	77,1	75,2	73,2	71,3	69,3
200	60,3	77,8	83,0	84,3	84,1	83,0	81,5	79,8	77,9	76,0	74,0	72,0	70,0
300	60,8	78,2	83,2	84,5	84,3	83,2	81,6	79,9	78,0	76,0	74,1	72,1	70,1
400	60,9	78,2	83,3	84,5	84,2	83,1	81,6	79,8	77,9	75,9	73,9	71,9	69,9
500	60,9	78,2	83,2	84,4	84,1	83,0	81,4	79,6	77,7	75,7	73,7	71,7	69,7
590	60,9	78,1	83,0	84,3	83,9	82,8	81,2	79,4	77,5	75,5	73,5	71,5	69,5

Table 6. Minimum efficiency values for horizontally mounted double suction (split chamber) rotodynamic pumps for clean water operation

Q_{do}	N_q														
(L/s)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
20	68,7	71,9	73,5	74,2	74,3	74,2	74,0	73,7	73,4	73,0	67,1	72,4	72,2	71,8	71,5
30	69,3	72,6	74,2	74,9	75,0	74,9	74,6	74,4	74,0	73,7	67,7	73,1	72,8	72,5	72,2
40	69,7	73,0	74,6	75,3	75,4	75,3	75,1	74,8	74,5	74,1	68,1	73,5	73,3	72,9	72,6
50	70,0	73,3	74,9	75,6	75,7	75,6	75,4	75,1	74,8	74,4	68,4	73,8	73,6	73,2	72,9
60	70,2	73,5	75,2	75,8	76,0	75,8	75,6	75,3	75,0	74,7	68,6	74,1	73,8	73,5	73,1
70	70,4	73,7	75,4	76,0	76,2	76,0	75,8	75,5	75,2	74,9	68,8	74,3	74,0	73,7	73,3
80	70,6	73,8	75,5	76,2	76,3	76,2	76,0	75,7	75,4	75,0	68,9	74,4	74,1	73,8	73,4
90	70,7	74,0	75,6	76,3	76,4	76,3	76,1	75,8	75,5	75,1	69,1	74,5	74,3	73,9	73,6
100	70,8	74,1	75,8	76,4	76,6	76,4	76,2	75,9	75,6	75,2	69,2	74,7	74,4	74,0	73,7
200	71,4	74,7	76,4	77,1	77,2	77,1	76,9	76,6	76,2	75,9	69,7	75,3	75,0	74,7	74,3
300	71,7	75,0	76,7	77,4	77,5	77,4	77,2	76,9	76,5	76,2	70,0	75,6	75,3	75,0	74,6
400	71,9	75,2	76,9	77,6	77,7	77,6	77,4	77,1	76,7	76,4	70,2	75,8	75,5	75,2	74,8
500	72,0	75,3	77,0	77,7	77,9	77,7	77,5	77,2	76,9	76,5	70,3	75,9	75,6	75,3	74,9
600	72,1	75,4	77,1	77,8	78,0	77,8	77,6	77,3	77,0	76,6	70,4	76,0	75,7	75,4	75,0
700	72,2	75,5	77,2	77,9	78,0	77,9	77,7	77,4	77,1	76,7	70,5	76,1	75,8	75,5	75,1
800	72,2	75,6	77,3	78,0	78,1	78,0	77,8	77,5	77,1	76,8	70,6	76,2	75,9	75,5	75,2
900	72,3	75,6	77,4	78,0	78,2	78,0	77,8	77,5	77,2	76,8	70,6	76,2	75,9	75,6	75,2
1000	72,3	75,7	77,4	78,1	78,2	78,1	77,9	77,6	77,2	76,9	70,7	76,3	76,0	75,7	75,3
2000	72,6	76,0	77,7	78,4	78,5	78,4	78,2	77,9	77,5	77,2	70,9	76,6	76,3	75,9	75,5
3000	72,7	76,1	77,8	78,5	78,7	78,5	78,3	78,0	77,7	77,3	71,0	76,7	76,4	76,1	75,7

Table 7. Minimum efficiency values for horizontal and vertical mounted rotodynamic pumps for wastewater operation

Q_{do}	N_q													
(L/s)	10	20	30	40	50	60	70	80	90	100	120	140	160	180
6,0	30,3	33,3	34,9	35,5	35,7	35,5	35,3	35,1	34,8	34,4	33,9	33,3	32,5	31,5
7,0	32,6	35,7	37,3	37,9	38,1	37,9	37,7	37,5	37,1	36,8	36,3	35,7	34,9	33,8
8,0	34,7	37,8	39,4	40,0	40,1	40,0	39,8	39,6	39,2	38,9	38,3	37,8	37,0	35,9
9,0	36,5	39,6	41,2	41,9	42,0	41,9	41,7	41,4	41,1	40,7	40,2	39,6	38,8	37,7
10,0	38,2	41,3	42,9	43,5	43,7	43,5	43,3	43,1	42,7	42,4	41,8	41,3	40,5	39,4
20,0	48,7	51,9	53,5	54,2	54,3	54,2	54,0	53,7	53,4	53,1	52,5	51,9	51,1	50,0
30,0	54,6	57,8	59,4	60,1	60,2	60,1	59,9	59,6	59,3	59,0	58,4	57,8	57,0	55,8
40,0	58,3	61,5	63,2	63,8	64,0	63,9	63,6	63,4	63,0	62,7	62,1	61,5	60,7	59,6
50,0	60,9	64,1	65,8	66,5	66,6	66,5	66,3	66,0	65,7	65,3	64,7	64,1	63,3	62,2
60,0	62,8	66,1	67,8	68,4	68,6	68,4	68,2	67,9	67,6	67,3	66,7	66,1	65,2	64,1
70,0	64,3	67,6	69,3	69,9	70,1	70,0	69,7	69,5	69,1	68,8	68,2	67,6	66,8	65,6
80,0	65,5	68,8	70,5	71,2	71,3	71,2	71,0	70,7	70,3	70,0	69,4	68,8	68,0	66,8
90,0	66,5	69,8	71,5	72,2	72,3	72,2	72,0	71,7	71,3	71,0	70,4	69,8	69,0	67,8
100,0	62,7	65,9	67,6	68,3	68,4	68,3	68,1	67,8	67,5	67,1	66,5	65,9	65,1	63,9
200,0	73,2	76,5	78,2	78,9	79,0	78,9	78,7	78,4	78,0	77,7	77,1	76,5	75,6	74,5
300,0	76,0	79,3	81,0	81,7	81,8	81,7	81,5	81,2	80,9	80,5	79,9	79,3	78,5	77,3
400,0	77,2	80,5	82,2	82,9	83,0	82,9	82,7	82,4	82,0	81,7	81,1	80,5	79,6	78,5
500,0	77,8	81,1	82,8	83,5	83,7	83,5	83,3	83,0	82,7	82,3	81,7	81,1	80,3	79,1
600,0	78,2	81,5	83,2	83,9	84,1	83,9	83,7	83,4	83,1	82,7	82,1	81,5	80,6	79,5
700,0	78,4	81,8	83,5	84,2	84,3	84,2	84,0	83,7	83,3	83,0	82,4	81,8	80,9	79,7
800,0	78,6	82,0	83,7	84,4	84,5	84,4	84,2	83,9	83,5	83,2	82,6	81,9	81,1	79,9
900,0	78,8	82,1	83,8	84,5	84,7	84,5	84,3	84,0	83,7	83,3	82,7	82,1	81,2	80,1

Table 8. Minimum efficiency values for horizontal and vertical mounted rotodynamic dewatering pumps

Q_{do} (L/s)	N_q										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**
7,0	36,4	39,5	41,4	42,2	42,4	42,2	42,0	41,6	41,3	40,9	40,5
8,0	37,2	41,4	43,1	43,8	44,0	43,8	43,6	43,3	42,9	42,5	42,1
9,0	38,0	42,6	44,5	45,2	45,4	45,3	45,0	44,7	44,3	43,9	43,6
10,0	38,9	43,4	45,7	46,5	46,6	46,5	46,2	45,9	45,5	45,2	44,8
20,0	47,4	51,7	53,7	54,5	54,6	54,5	54,2	53,9	53,5	53,2	52,8
30,0	52,7	56,7	58,7	59,5	59,6	59,5	59,2	58,9	58,5	58,2	57,8
40,0	56,7	60,3	62,1	62,8	63,0	62,9	62,6	62,3	61,9	61,6	61,2
50,0	59,2	62,9	64,7	65,4	65,6	65,4	65,2	64,9	64,5	64,1	63,8
60,0	60,1	64,6	66,7	67,5	67,6	67,5	67,2	66,9	66,6	66,2	65,9

4 Conclusions

This paper proposes a new methodology for estimating the minimum or reference efficiency of rotodynamic pumps. It is based on current international standards and research conducted over nearly 20 years at the Center for Hydraulic Research (CIH) on this topic. Having a domestically developed procedure will ensure that the rotodynamic pumps selected for import into the country, as well as those manufactured in Cuba, are the most efficient within each design group of rotodynamic pumps available on the market.

The new methodology takes as its starting point Resolution No. 655/2009 of the Ministry of Construction (MICONS), currently in force in our country for the selection of rotodynamic pumping equipment. After a thorough critical review, describing its main conceptual, approach, numerical, and calculation procedure limitations, this updated proposal corrects all of these shortcomings, as well as those related to its practical implementation.

Ten reference models were analyzed to obtain the dimensionless efficiency for 75%, 100%, and 110% of the dimensionless design flow rate (operational efficiency) for single-stage horizontally mounted pump groups and multi-stage vertically mounted pumps (ring-type and bowl pumps). Finally, the references to be used for calculating efficiency at these three reference points were defined. Verification criteria for operational efficiency were introduced for the partial load (PL) and overload (OL) points, η_{OLr}, and the specific speed range was expanded for ring-type and dewatering pumps.

Similarly, efficiency values for double-suction pumps, which were not included in the aforementioned resolution, are presented. An expansion and a new distribution by design type for rotodynamic pumps are carried out, proposing new, more precise values for their minimum efficiency. A redefinition of the concept of the optimum specific speed range, characterized by design groups of rotodynamic pumps, is added. It is established that the optimum specific speed range for pumps with volute and ring casings is 35 to 65, while for those with bowl casings, it is between 85 and 115, with their optimum values being 50 and 95, respectively.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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Participated in the development of the methodological proposal for Cuban regulations on estimating the efficiency of rotodynamic pumping equipment.

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Worked on processing the case study data, contributing to its analysis and interpretation. Participated in the information search and final drafting of the paper.